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WHEAT—ITS PROTEINS AND NUTRITIONAL PROPERTIES

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For many years the proteins of wheat have been the subject of extensive investigation. Volumes could be written on them. It is not the author's purpose to dwell in detail upon a review of the earlier work on wheat proteins; neither shall he enter into a discussion of such questions as the constitution and individuality of the wheat proteins, their physico-chemical properties, or questions bearing on the relation of the proteins to the subject of weak and strong flours. These phases of the chemistry of wheat proteins have been studied comparatively recently and the results reported in numerous publications by Gortner, Bailey, Blish, and others. This discussion will be confined primarily to the different types of proteins in the wheat kernel, their amino acid composition, and their nutritive properties.

The pioneer work of Osborne on the proteins of the wheat kernel established the nature and the different types of proteins found in wheat, and the approximate quantities in which they are present. Studies on the different parts of the wheat kernel, namely, the endosperm, germ, and bran, have revealed characteristic differences in their proteins. The proteins of the endosperm consist chiefly of gliadin and glutenin, present in approximately the same but somewhat varying proportions, depending on the variety of the wheat and the environmental conditions under which it is grown. Gliadin belongs to the class of proteins called prolamins. Osborne first proposed this name for those plant proteins which are soluble in aqueous alcohol and which yield on hydrolysis relatively large amounts of the amino acid proline and amide-nitrogen. Glutenin is a representative of the glutelins, a class name proposed by the American Committee on Protein Nomenclature for those seed proteins which are insoluble in neutral solutions but soluble in dilute acids or alkalies. It is of interest to note that the presence of these two classes as the pre-

dominating proteins is peculiarly characteristic of wheat and most cereals. Prolamin has not been found in any significant amount in any plant material other than the cereal grains. Although glutelins have been isolated from other seeds, such as legume seeds, they are not one of the predominating proteins present. It is questionable whether they really are glutelins or whether they represent small proportions of other denatured proteins. The predominating proteins in most seeds other than the cereal grains are globulins.

The amounts of globulin, albumin and proteose generally found in the wheat endosperm are so small as to indicate that they may not be constituents of the endosperm, but represent proteins from other parts of the kernel which are incompletely separated by the milling process. This conclusion is supported by the fact that these proteins closely agree in their composition with those isolated from the embryo. Recent work by Hoffman and Gortner (1927) led them to conclude that the presence of a true globulin in wheat flour is problematical. They did, however, isolate considerable amount of a fraction having the properties of an albumin. No proteose was found.

In general, the proteins of the endosperm of seeds may be regarded as inactive reserve proteins stored as nutritional material required for the development of the young plant. Under conditions of temperature and moisture favorable for germination, proteolytic enzymes present in the seed become active and the complex, highly developed proteins of the endosperm are converted into nitrogenous compounds, which are more soluble and more available for assimilation by the young plant.

The proteins of the embryo, on the other hand, more closely resemble the proteins of the physiologically active animal tissues, with respect to chemical composition and physical properties. The proteins of the wheat embryo consist of albumin, globulin and proteose. The albumin, leucosin, amounts to about 10% of the embryo, and represents the greater part of the total embryo protein. Osborne and Campbell (1900) also isolated from wheat embryo upwards of 5% globulin. They further isolated from the embryo a considerable amount of proteose. Whether the proteose exists preformed in the embryo or is a product of hydrolysis of other proteins brought about by the action of proteolytic enzymes was not definitely established. They found that many of the albumin and globulin preparations isolated from the embryo had properties commonly ascribed to nucleoproteins, and that they were salt-like compounds of the proteins and nucleic acid which could be separated from their constituents only with great difficulty.

More recently the proteins of wheat bran have been isolated and studied both chemically and biologically. Approximately 22% of the nitrogen of the wheat kernel resides in the seed coats or bran. The bran

proteins consist of a globulin, albumin, and a prolamin. These proteins differ essentially from the corresponding proteins of the endosperm and embryo, both with respect to their elementary analyses and to their amino acid composition. Of the total protein of the bran the albumin represents 16%, the globulin 13%, and the prolamin 31%.

The proteins of the endosperm consist almost, if not entirely, of a prolamin and a glutelin, while the embryo proteins consist almost entirely of a globulin and an albumin. The bran proteins, on the other hand, consist of albumin, prolamin and globulin, but no glutenin.

The proteins of the different parts of the wheat kernel differ from each other not only with respect to their types and physical properties but also with respect to their elementary composition and their amino acid composition (Tables I and II). Most amino acids known to be hydrolytic products of proteins have been determined in the two endo-

TABLE I

ELEMENTARY COMPOSITION OF WHEAT PROTEINS[1]

	Carbon	Hydrogen	Nitrogen	Sulfur
	%	%	%	%
Prolamins				
Wheat gliadin	52.72	6.86	17.66	1.02
Bran prolamin	54.25	6.75	15.35	1.35
Albumins				
Leucosin	53.01	6.83	16.93	1.30
Bran albumin	53.21	6.71	15.42	1.35
Globulins				
Bran globulin	53.43	7.40	17.76	0.91
Embryo globulin	51.03	6.85	18.39	0.69
Glutelin				
Wheat glutenin	52.34	6.83	17.49	1.08

[1] The figures for the bran proteins are those of Jones and Gersdorff (1923); those for the endosperm and embryo proteins are those of Osborne and Voorhees (1893).

sperm proteins, gliadin and glutenin. Of the proteins of the embryo only the albumin leucosin has been analyzed for its amino acid content. No data are available regarding the percentages of amino acids in the embryo globulin. A number of amino acids have been determined in the prolamin, albumin and globulin of the bran.

In order to compare the amino acid composition of the different proteins in the same parts of the wheat kernel, and also the composition of the same classes of proteins in the different parts of the kernel, there are shown in Tables II and III percentages of those amino acids which have been determined in the proteins isolated from the endosperm, embryo and bran. Three of these amino acids, namely, histidine, lysine, and tryptophane, are known to be indispensable for the growth of animals. Until the recent work of Jackson and Block (1932) and of Rose et al. (1936), cystine has also been regarded as an indispensable amino

acid, but now it seems that cystine can be replaced in the diet by methionine.

These figures are of interest because they show not only that the wheat kernel contains a diversity of different classes of proteins, but that these proteins differ in their amino acid composition not only with respect to classes but also with respect to the same class in the different parts of the seed.

TABLE II

COMPARISON OF THE AMINO ACID COMPOSITION OF THE PROTEINS IN THE DIFFERENT PARTS OF THE WHEAT KERNEL

	Cystine	Arginine	Histidine	Lysine	Trypto-phane	Tyrosine	Basic nitrogen
	%	%	%	%	%	%	%
Endosperm proteins							
Gliadin	2.04[1]	2.97[3]	2.19[3]	0.64[3]	1.09[2]	2.65[1]	1.00
Glutenin	0.60[1]	4.72[4]	1.76[4]	1.92[4]	1.72[2]	4.78[1]	2.05
Embryo proteins							
Leucosin	—	5.94[4]	2.83[4]	2.75[4]	—	3.34[4]	3.50
Globulin	—	—	—	—	—	—	6.83
Bran proteins							
Prolamin	2.29[1]	4.41[5]	0.84[5]	2.45[5]	1.37[2]	1.80[1]	
Globulin	1.52[1]	14.13[5]	2.76[5]	11.84[5]	2.85[2]	2.27[1]	
Albumin	3.30[1]	10.04[5]	2.57[5]	4.51[5]	4.76[2]	4.52[1]	

[1] Jones and Gersdorff (unpublished).
[2] Jones, Gersdorff, and Moeller (1924).
[3] Osborne, Van Slyke, Leavenworth, and Vinograd (1915).
[4] Osborne and Clapp (1906).
[5] Jones and Gersdorff (1925).

The most conspicuous difference between the endosperm proteins (Table II), gliadin and glutenin, with respect to their nutritional value, lies in their lysine, cystine and tyrosine content. The earliest determinations of lysine in gliadin were made by the isolation method of Kossel and Kutcher. They gave a value of 0.13%. It was for years a debated question whether gliadin itself contained any lysine or whether the small amount of lysine isolated was derived from some contaminating protein. Later, by hydrolyzing a large quantity of gliadin Osborne (1915) was able to isolate 0.64% of lysine. Subsequently 1.21% was obtained by the gasometric method of Van Slyke. Inasmuch as the results obtained by the Kossel method are unquestionably somewhat too low, and those by the Van Slyke method may be too high, Osborne concluded that the actual amount of lysine in gliadin is probably not far from the average of the two figures, namely, 0.92%. Lysine has been shown by feeding experiments to be the limiting factor in the protein nutritional value of gliadin. Glutenin, on the other hand, contains considerably more lysine, and nearly twice as much tyrosine, but only about one-third as much cystine.

Unfortunately, no data are available on the amino acid composition of the globulin of the wheat embryo. The percentage of basic nitrogen, however, is nearly twice as high as that for leucosin. The basic nitrogen represents the nitrogen of the amino acids which are precipitable by phosphotungstic acid, and which include arginine, histidine, lysine and cystine.

Again, we find wide differences in the amino acid content of the bran proteins, the most notable of which are the figures for arginine, histidine and lysine. Attention is called particularly to the high percentages of lysine.

The percentages shown in Table II are rearranged in Table III in

TABLE III

COMPARISON OF THE AMINO ACID COMPOSITION OF THE SAME CLASSES OF PROTEINS IN THE DIFFERENT PARTS OF THE WHEAT KERNEL

	Cystine	Arginine	Histidine	Lysine	Trypto-phane	Tyrosine	Basic nitrogen
	%	%	%	%	%	%	%
Prolamins							
Endosperm (gliadin)....	2.04	2.97	2.19	0.64	1.09	2.65	1.00
Bran.....	2.29	4.41	0.84	2.45	1.37	1.80	2.30
Embryo.....							
Albumins							
Endosperm...							
Bran.....	3.30	10.04	2.57	4.51	4.76	4.52	5.12
Embryo (leucosin)...	—	5.94	2.83	2.75	—	3.34	3.50
Globulins							
Endosperm...	—	—	—	—	—	—	—
Bran.....	1.52	14.13	2.76	11.84	2.85	2.27	7.73
Embryo.....	—	—	—	—	—	—	6.83
Glutelins							
Endosperm (glutenin)..	0.60	4.72	1.76	1.92	1.72	4.78	2.05
Bran.....							
Embryo.....							

order to show more clearly the differences in the composition of the same classes of proteins as they occur in the different parts of the wheat kernel.

Prolamins have been obtained only from the endosperm and the bran. The differences in the percentages of some of the amino acids, particularly those for histidine and lysine indicate clearly that these prolamins of the bran and endosperm are two different proteins.

Representatives of the albumin class found in the embryo and the bran are differentiated primarily in their content of arginine. No fig-

ures are available showing how much cystine and tryptophane there are in leucosin, the embryo albumin.

No comparison can be made between the globulins of the bran and those of the embryo, because the amino acids of the embryo globulin have not been determined.

Glutenin, of the endosperm, is the only representative of the glutelins found in the wheat kernel.

It should be pointed out that the percentages given in Tables II and III for arginine and histidine in gliadin, and those for arginine, histidine and lysine in the wheat bran proteins are based on analyses made by the Van Slyke method. The percentages for lysine in gliadin, arginine, histidine and lysine in both glutenin and in leucosin are based on isolation determinations. The results obtained by the Van Slyke method may be somewhat higher than the actual values, while those obtained by isolation are doubtless low in many cases. Consequently, when comparing the figures in Tables II and III these considerations should be kept in mind. However, the differences which have been emphasized in the foregoing discussion between the percentages of these amino acids in the various proteins are far greater than can be justly ascribed to the two methods of analysis. All the determinations of cystine, tryptophane, and tyrosine were made colorimetrically and therefore are strictly comparable.

It is of interest to note in connection with the amino acid content of the wheat proteins that gliadin contains the highest percentage of glutamic acid that has been found in any protein. By actual isolation gliadin has yielded 43% of this amino acid (Jones and Wilson, 1928).

The nutritive value of a protein depends primarily on its amino acid composition. If it is lacking or deficient in any one of the dietary essential amino acids animals will not grow satisfactorily. Furthermore, these amino acids must be present in a way so that they are available for assimilation. The amino acids in some proteins are not available because they are almost wholly undigested by most animals. Other proteins largely digestible are not adequate sources of one or more amino acids even when they are present in the protein. The amino acids in these proteins seem to be tied up in the molecule in some way so that they are not available for assimilation. The amino acid composition of a protein, therefore, may be an unreliable criterion of its nutritive value. Some legume seed proteins will not support growth in young rats unless they are supplemented with cystine, although analyses show that they contain cystine in amounts which should be adequate. In discussing the nutritive value of the wheat proteins attention should be given both to their amino acid composition and to the results of actual feeding experiments.

It has been pointed out that gliadin is low in lysine but contains a fairly large amount of cystine. Glutenin, on the other hand, is low in cystine, but contains about 2% lysine. The results of feeding experiments are in accord with these values. Several investigators have studied the biological properties of gliadin. Animals fed a diet with gliadin as the sole source of protein will not grow because they do not get enough lysine. Glutenin, on the other hand, containing nearly 2% of lysine, supports growth fairly satisfactorily. It, therefore, seems probable that the wheat endosperm proteins as a whole do not fall very short of constituting an adequate source of lysine. The relatively low cystine content of glutenin is compensated for by the much higher percentage present in the gliadin. That the cystine of gliadin is probably available is indicated by the high degree of digestibility of gliadin as found by Mendel and Fine (1911–1912). The results of feeding experiments by several investigators, however, are pretty well in accord that the wheat endosperm proteins alone are not entirely satisfactory to meet the protein nutritional requirements of animals.

There are several amino acids other than those here discussed which recently have been shown to be nutritionally essential—leucine, isoleucine, valine, phenylalanine, amino-hydroxybutyric acid, and methionine. Because of the meager data available on the amounts present in proteins, these amino acids can not now enter into the present discussion on the nutritional properties of the wheat proteins.

The crude proteins of the wheat embryo have been found more efficient than those of the entire kernel for promoting growth, and decidedly more efficient than those of the endosperm.

The proteins of wheat bran have long been recognized by feeders of farm animals to have high nutritive value. Osborne and Mendel (1919) in feeding experiments with rats were the first to make a critical study of the value of wheat bran as a source of protein. They found that upward to 75% of the nitrogen of the bran was utilized. They state that "the crude protein of wheat bran has a higher value for the growing animal than does that of the embryo. . . . The crude protein of bran appears to be quite as efficient as that of the combination of wheat flour with egg, milk, or meat under the conditions of this experiment."

The high percentages of nutritionally-essential amino acids found in the isolated proteins of bran have been referred to already. Feeding experiments conducted in the Bureau of Chemistry and Soils (Murphy and Jones, 1926) showed that the proteins of wheat bran promote rapid growth in young rats when bran constitutes the sole source of protein in the basal ration (Figure 1). In other experiments using the same diet rats were raised from the time they were weaned until they reached

maturity. Throughout this period they remained in a state of good nutrition. These results demonstrate that wheat bran is efficiently utilized by rats as a source of protein of high nutritional value. They also refute the statement sometimes seen that only ruminants can utilize the proteins of wheat bran.

An interesting observation was made in feeding experiments designed to compare the nutritive properties of the proteins of bran with those of the endosperm. In Figure 2 the continuous lines represent the rate of growth when bran was fed as the sole source of protein in the diet. The broken lines represent the rate of growth when white flour supplied

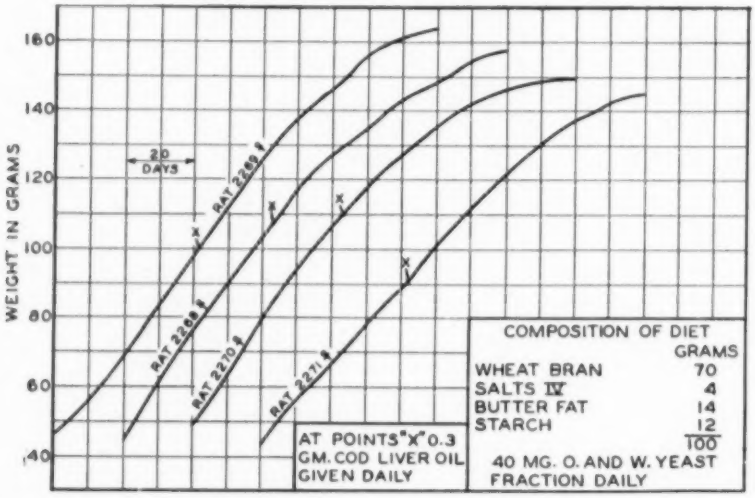

Figure 1. Rate of growth of rats on a diet containing commercial wheat bran as a source of protein. The bran furnished 9.9% of crude protein.

the endosperm proteins. The animals grew rapidly on the bran diet for about 15 weeks. Thereafter there was a characteristic falling off in the rate of growth. Growth rate on the flour diet, on the other hand, was much slower during the same period, but the rate continued uniformly until it caught up with and exceeded that of the animals on the bran diet. At the end of 240 days the rats on the flour diet weighed more than those on the bran diet. It appears that there is something in the bran not present to the same extent in the flour which is conducive to rapid growth in the young, but that the endosperm provides for better maintenance in the adult. To what factor or factors this difference can be attributed can not definitely be stated at present. Osborne and Mendel long ago pointed out that lysine is essential for growth and that tryptophane is essential for maintenance. The method commonly used to find out whether an amino acid is indispensable is to determine its

capacity to promote the growth of young animals. It is probable that the so-called essential amino acids may have specific functions in the life history of an animal aside from promoting growth in the young, and that the amino acids which have not yet been demonstrated to be "essential" will be found to have as yet unrecognized specific functions when they are studied throughout the entire life span of several generations.

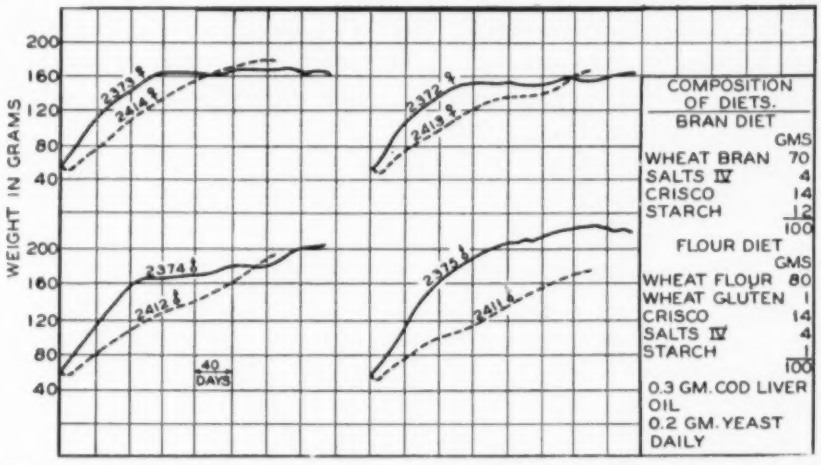

Figure 2. Comparison of the rate of growth of rats on diets containing wheat bran and white flour as sources of protein ——— bran diet – – – – – flour diet.

It is evident from the foregoing brief resume on the proteins of wheat and their amino acid content that the picture is far from complete. Little definite knowledge is available regarding several of the wheat proteins either with reference to the relative proportions in which they are present in the kernel or with reference to their amino acid content. A question frequently met in correspondence of the Bureau of Chemistry and Soils is, how much is there of this and of that amino acid in corn, wheat or oats? The owner of a fur farm who may have read somewhere that cystine is an important amino acid for the production of fur wants to know how much cystine there is in certain foods used for feeding foxes. Unfortunately, no satisfactory answer can be given. The methods used for determining amino acids can be satisfactorily applied only to isolated purified proteins. Interfering substances, such as starches and fats, preclude their application to the quantitative analyses of foodstuffs. This presents a very important problem. The feeder or consumer is concerned with the amount of the amino acids in corn, wheat, or barley as these foods are used. It helps him little to tell him how much lysine or tryptophane there is in zein, or gliadin, or hordein.

F. A. Csonka of the Bureau of Chemistry and Soils has been working recently to develop a method whereby some of the more important amino acids can be determined in whole seeds or foodstuffs. Working on the whole kernels of a hard spring and a hard winter wheat, and on a 74% patent flour milled from the same wheat samples, he found appreciably more lysine, histidine, tyrosine and arginine in the whole wheat flours than in the patent flours. There was not a great difference found in the cystine and tryptophane content of the patent flour and of the whole wheat flour. Higher percentages of all the amino acids were found in the hard spring wheat flours than in the hard winter wheat flours. The results of these determinations have been published recently (Csonka, 1937).

The writer is glad to be able to report here the results of some methionine and cystine determinations handed him by M. J. Horn just before

TABLE IV

CYSTINE AND METHIONINE CONTENT OF WHOLE WHEAT AND PATENT FLOUR, AND OF THE ISOLATED PROTEINS OF WHEAT

	Cystine	Methionine
	%	%
Whole wheat	0.19	0.10
Patent flour	0.24	0.48
Gliadin	1.96	1.28
Glutenin	1.23	1.56
Bran globulin	0.66	0.26
Bran prolamin	1.86	1.15
Bran albumin	2.00	1.19

leaving Washington. Methionine is one of the more recently discovered amino acid components of proteins. It was in 1932 that it was found to cause a specific growth response. Comparatively few proteins have been analyzed for this amino acid. Dr. Horn's determinations were made on whole wheat and on a patent flour milled from the same wheat. Determinations were also made on samples of purified isolated wheat proteins which had been prepared in connection with previous studies. These figures are of interest in several respects. As far as we are aware, they are the only figures that have been reported on the methionine content of the different wheat proteins. In the case of the whole wheat and of the patent flour, it is the first time the method has been applied to the determination of methionine in products other than isolated, purified proteins. The determinations were made according to Baernstein's method (1936) with slight modifications. The results are given in Table IV. The figures for cystine in the whole wheat and in the flour are in close agreement with those determined by Csonka (1937) for a hard winter wheat by an entirely different method. Although

these figures represent average values of closely agreeing results of several determinations, they are here recorded as preliminary, tentative values. Further work will be done to establish the reliability of the method as applied to meals and flours.

In conclusion, a cursory review of our present knowledge on the proteins of wheat and their nutritive properties emphasizes the fact that much remains to be found out. Available evidence, however, shows that wheat, proverbially considered the "staff of life," still retains its front rank among the cereals as a source of dietary protein. Since the work of Osborne and Mendel (1919), little, if any, evidence has been produced to invalidate their following conclusions:

> "Wheat proteins considered in their entirety are adequate for promoting normal growth if eaten in sufficient amount. . . . The proteins of the entire wheat kernel suffice to promote the growth of rats to normal adult size. . . . The proteins of the wheat kernel are not greatly inferior to casein, edestin, or even to the total proteins of milk."

Summary

A review is given of our present knowledge of the different classes of proteins in the wheat kernel. The percentages of amino acids which have been determined in the wheat proteins are compared both with respect to the same classes of proteins (prolamin, albumin, glutelin, globulin) in the same parts of the kernel (endosperm, embryo, bran) and with respect to these proteins in the different parts of the kernel. The same classes of proteins occurring in the endosperm and bran differ widely in their amino acid composition. The nutritional properties of the different wheat proteins are discussed. New figures are given for the cystine and methionine content both for the isolated wheat proteins and for the whole wheat.

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FACTOR CONTROL IN CAKE BAKING

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(Read at the Annual Meeting, May 1937)

In the development of any standard baking test, there are many factors which must be kept under strict control in order to avoid variability in results. Unless the control of such factors is adequate, it is difficult to draw conclusions from the results obtained under the baking test. Some of these factors are well known to cereal chemists and a survey of the literature indicates that the better-known variable factors are under the best control.

The Committee on Cake Baking Tests has annually reported on various phases of the development of a standard cake-baking test, with the principal objective in mind of developing a test for cake flours. This committee has quite rightfully devoted its efforts to the development of a test built around a leavened cake.

In testing other cake-making ingredients, it does not necessarily follow that such a test will reveal all of the information desired. In evaluating shortening, for example, a test built around a relatively lean pound cake which contains no leavening agent has much to recommend it, because all of the volume obtained under such a pound-cake test bears a direct relation to the creaming behavior of a shortening. Physical measurements made on the creamed mass and on the finished cake batter add considerably to the information obtained under this cake test.

The idea of taking physical measurements at various stages during the mixing procedure is not new. The Subcommittee on Shortening of the American Society of Bakery Engineers (1933) pointed out the advisability of measuring the creaming volume, and three suggested methods of obtaining this information were outlined. One of these methods has been further developed and standardized and is recommended because of simplicity, speed, and accuracy.

Figure 1 (a–f) shows the method in detail. It requires only about one minute to obtain a measurement of the specific volume (the reciprocal of the density) of the creamed mass. After a reasonable amount of experience with this method, two different operators can check themselves on the same creamed mass within ± 0.02.

Fisher (1936) reported specific gravities of cake batters and roughly outlined a method for obtaining such measurements. The method

Figure 1a. The cup is half filled with the cream or batter and is tapped smartly down on a folded towel 12 times. Between each two taps, the cup is rotated about 30°.

Figure 1b. The cup is then filled more than full. The excess cream or batter is peaked toward the center.

Figure 1c. The cup is once more tapped 12 times, rotating as before.

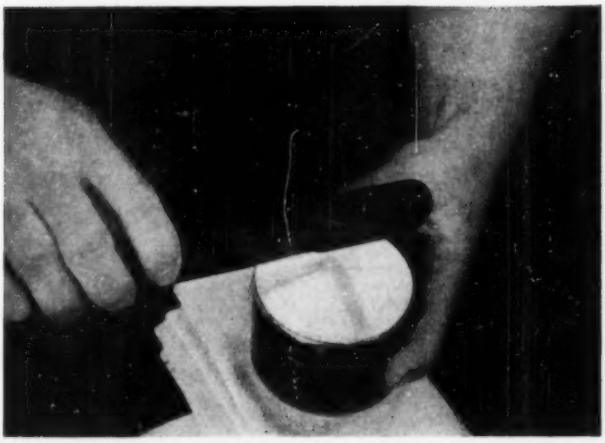


Figure 1d. Half the excess cream is scraped off, starting with the spatula in the center. Then half of the remaining excess cream is scraped off toward the edge. Finally, the last quarter is removed.

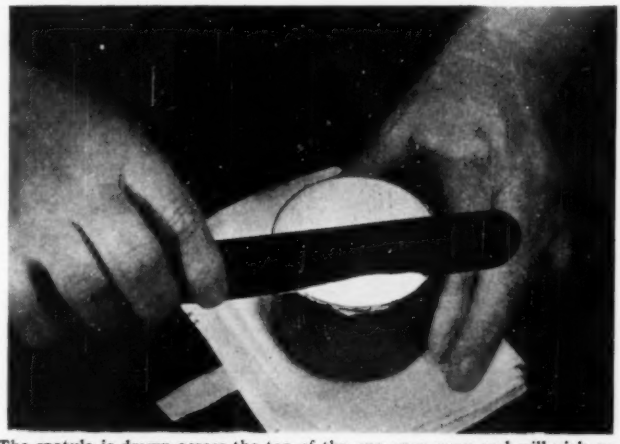


Figure 1e. The spatula is drawn across the top of the cup once more and will pick up just a small amount of cream. The cup is then wiped to clean off the edge.

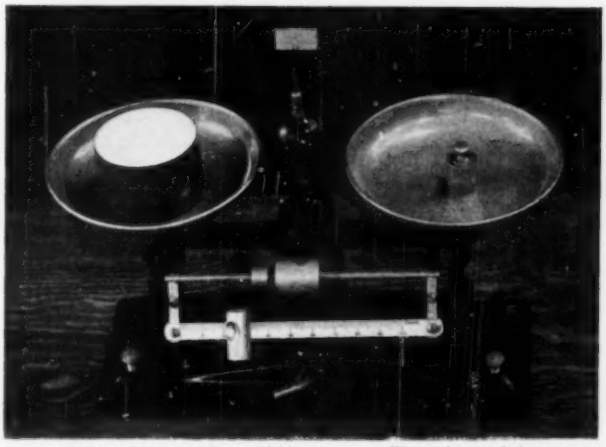


Figure 1f. The cup is weighed accurately to within 1 gram. The volume of the cup being known, the specific volume $\left(\frac{1}{\text{Sp. G.}}\right)$ or lightness is calculated.

which we recommend would appear to be simpler and we believe it to be sufficiently accurate for all practical purposes.

A factor study of a pound-cake test method has been made and information obtained which would appear to be generally applicable to all cake testing. These ideas are here presented with the hope that our experience may be helpful to others working in similar fields.

Experimental

What Should a Cake Test Reveal About Shortening?

Shortenings should cream well, because upon their creaming behavior the lightness of cakes and other baked goods, and of icings as well, primarily depends. The cream should be sturdy so that when the liquid and flour are added the creamed structure will be able to support these heavier ingredients. By measuring the specific volume of the creamed mass and of the batters, as well as the volume of the finished cake, it is not difficult to score a shortening for the various uses to which it may be applied in industry.

Some Typical Pound-Cake Data

In Table I pound-cake data are given for a number of characteristic shortenings. These data show that high creaming volume is not

TABLE I

Typical Pound-Cake Data

Specific volume of cream	Specific volume of dough	Loaf volume in c.c.
1.88	1.39	3023
1.67	1.38	3000
1.97	1.40	2985
1.90	1.33	2841
1.85	1.27	2777
1.64	1.31	2765
1.82	1.24	2700
1.81	1.26	2633
1.61	1.18	2494
0.93	0.90	1700
1.05	0.91	1628

always associated with high dough volume and loaf volume. It is also evident that certain shortenings showing high dough volume and loaf volume may be deficient in creaming property. Certain of these data are shown graphically in Figures 2, 2a, and 2b. The curve *A* represents a high-quality shortening well adapted for icings, cakes and general bakery production. Curve *B* represents an average shortening in the general baking field. Curve *C* represents a shortening with good cake-making properties but deficient in creaming volume. Such

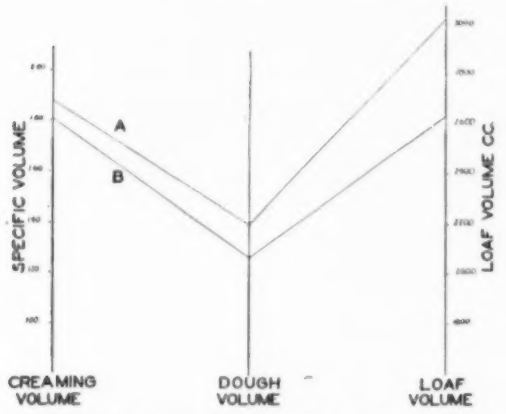


Figure 2. Cake making characteristics of typical shortenings.

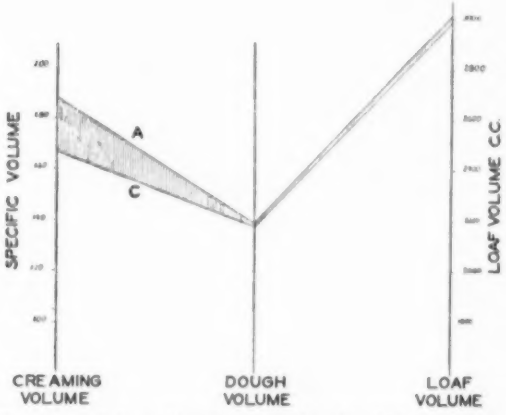


Figure 2a. Cake making characteristics of typical shortenings.

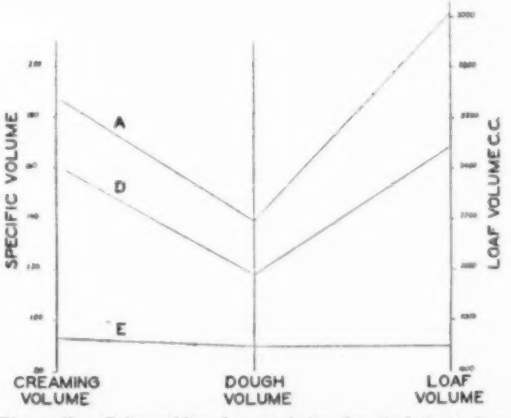


Figure 2b. Cake making characteristics of typical shortenings.

shortening does not give adequate lightness in creamed icings. Curve *D* represents a typical compound and Curve *E* represents a prime steam lard.

A study of typical pound-cake data covering some 50 shortenings (selected by type to cover the entire field) was made, to determine whether the creaming volume of a shortening bears a direct relation to the finished cake volume.

In Figure 3 specific volumes are compared as ordinates with the corresponding loaf volumes as abscissas. The general relationship

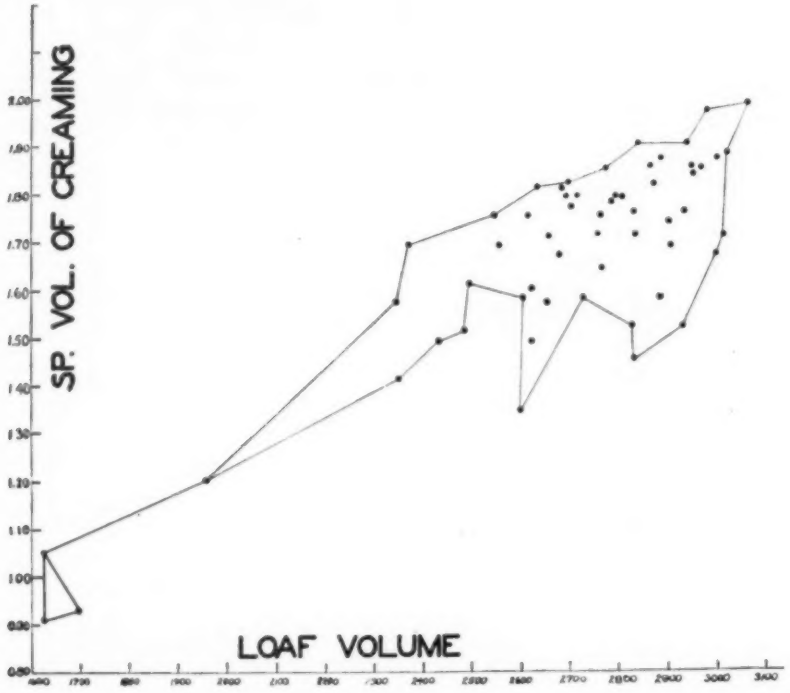


Figure 3. Relation of creaming volume to loaf volume.

is apparent, but it is obvious that in many instances shortenings do not tend to follow a straight-line relationship.

In Figure 4 the dough volumes are compared with loaf volumes. In this case the direct straight-line relationship is much more apparent. It should be noted that the ordinate units represent half the value of those in Figure 3. Had the same scale been used, the curve would represent a straight-line function even more closely. It is apparent, therefore, that there is a very close correlation between the lightness of pound-cake batter and the volume of a finished cake.

Standardizing the Pound-Cake Test

In attempting to standardize a baking test among a number of laboratories located in different sections of the country, many factors must be carefully controlled. Probably the first and most important of these factors is the granulation of the sugar used in the creaming test. The effect of sugar granulation on the creaming process was probably first called to the attention of bakers and cereal chemists by Minton (1929 and 1931). The importance of sugar granulation has also been discussed by Bailey and LeClerc (1935). Stokes and Track (1936) have discussed the relationship between crystalline sugar and dissolved sugar under the A. A. C. C. basic formula for testing cake flours.

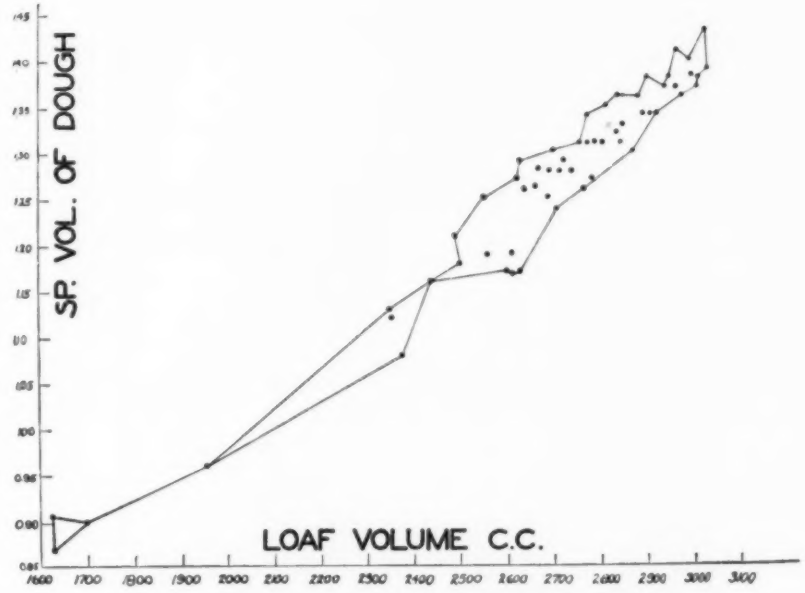


Figure 4. Relation of dough volume to loaf volume.

Since the granulation is of such apparent importance in standardized cake methods, samples of 8 commercial sugars varying in size from a very coarse topping sugar (such as ordinarily used as a topping for sugar cookies) to 6X Confectioners' powdered sugar were obtained. Table II shows the results when these sugars were tested under the standard pound-cake test, other factors being kept constant.

It is apparent that the creaming, dough, and loaf volumes are poor with the very coarse sugars and that they become better and better as the granulation becomes finer. Thus, fruit-powdered granulated sugar gives the highest values. It should be noted that since the

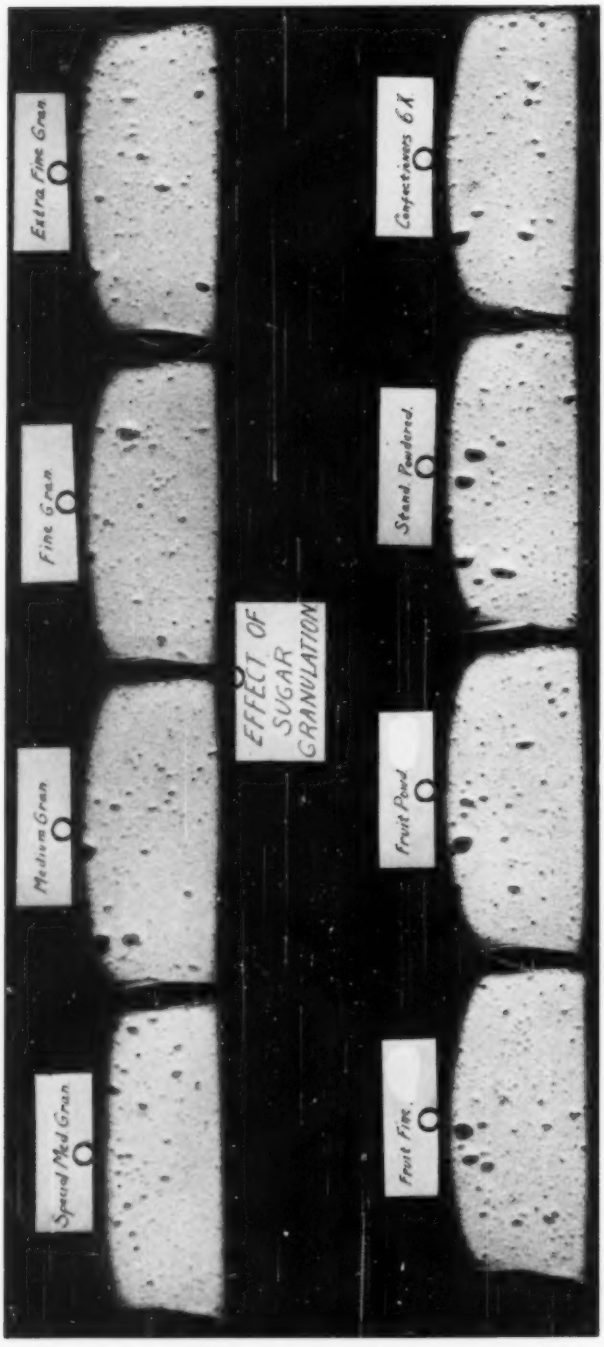


Figure 5. Effect of sugar granulation.

TABLE II

EFFECT OF SUGAR GRANULATION ON CAKE CHARACTERISTICS

Grade of sugar	"A" or "O" topping sugar	Medium granulated	Fine granulated	Extra-fine granulated	Fruit-fine granulated	Fruit-powdered granulated	Standard powdered	6X confectioners' powdered
Specific volume of preliminary cream—before eggs are added	1.025	1.19	1.345	1.36	1.40	1.44	1.35	1.09
Specific volume of finished cream	1.28	1.49	1.66	1.78	1.79	1.84	1.75	1.47
Specific volume of dough	1.19	1.28	1.30	1.32	1.33	1.345	1.32	1.28
Loaf volume in c.c.	2438	2685	2689	2754	2758	2792	2738	2695

crystalline structure of sugar is ruptured by grinding, the cake-making properties fall off distinctly. Thus, standard-powdered gives poorer results than fruit-powdered, although there is not much difference in particle size between these two grades. The chief distinction between these two powders is that fruit-powdered is a crystalline sugar, whereas standard-powdered is a ground sugar. The cakes resulting from these tests are shown in Figure 5.

SUGAR GRANULATION SPECIFICATIONS

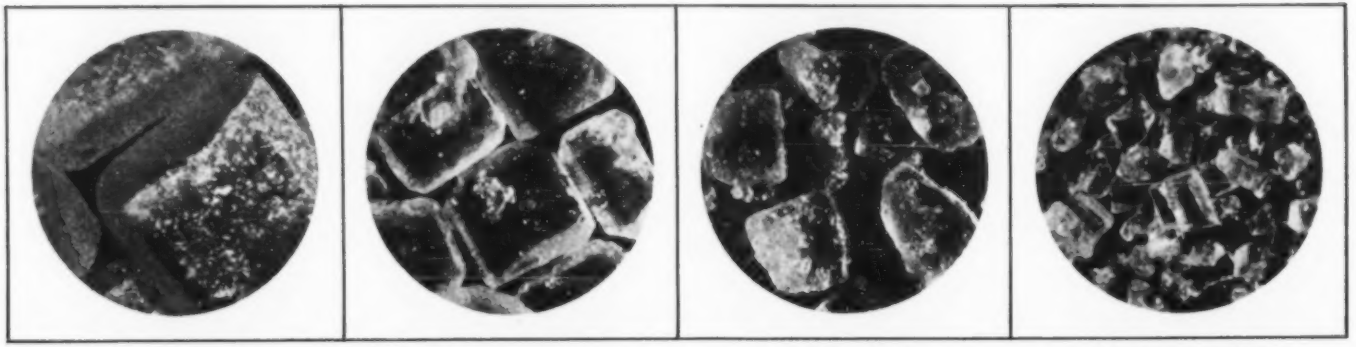
Through the courtesy of a sugar refinery, the granulation specifications on these 10 grades of sugar were obtained and are given in Table III. An estimated United States consumption by grades was also obtained from the same source and is also shown in Table III. It is

TABLE III

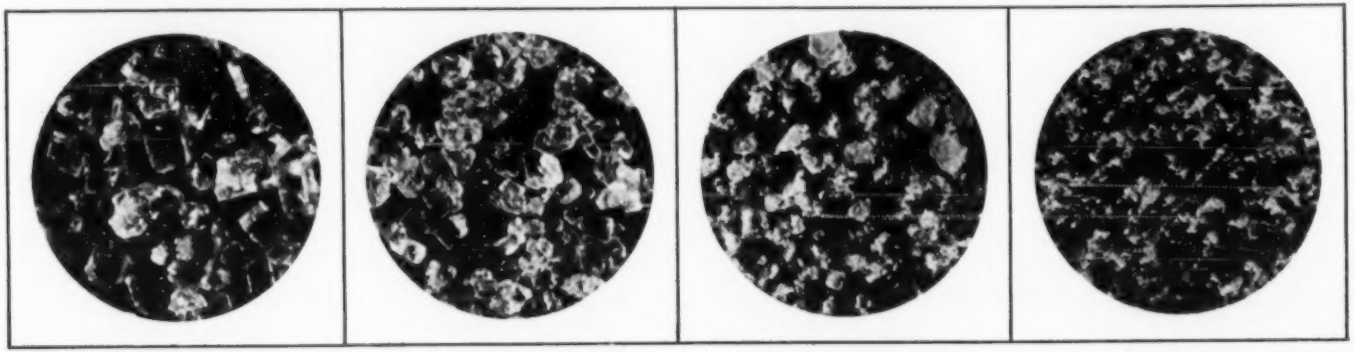
SUGAR GRANULATION SPECIFICATIONS

Grade	Topping sugar	Common granulations			Cake sugars		Powdered grades		
	Standard medium "O" or "A"	Medium	Fine	Extra fine	Fruit fine	Fruit powdered	Standard powdered	4X	6X
	%	%	%	%	%	%	%	%	%
10 mesh		0.9							
14 mesh	40	2.0							
20 mesh	60	13.0							
28 mesh			7						
35 mesh		66.0	55	8	3	0.4			
48 mesh		17 (1%)[1]	20	25	18	8.4			
65 mesh			9	30	35	27.3	25		
100 mesh			5 (4%)[1]	25 (12%)[1]	29 (15%)[1]	44.6 (19.3%)[1]	17 (57%)[1]	2	1
150 mesh								4	2
200 mesh								12 (82%)[1]	6 (91%)[1]
Estimated proportion of total U. S. sugar consumption by grades	0.6	7.5	8.1	67.9	10.1	0.05	0.14	4X plus 6X taken together 5.37%	

[1] "Throughs" shown in parenthesis.



"A" or "O" Topping | Medium Granulated | Fine Granulated | Extra-Fine Granulated



Fruit-Fine Granulated | Fruit-Powdered Granulated | Standard Powdered | 6 X Powdered

Figure 6. Photomicrographs of eight common grades of sugar (×20).

thus apparent that approximately 78% of all sugar consumed in the United States is confined to two grades, namely, extra-fine granulated and fruit-fine granulated. These two grades, therefore, are the granulated sugars with which we may expect to be dealing in cake production.

When the granulation specifications of extra-fine granulated and fruit-fine granulated are compared, it is apparent that the chief difference between these two sugars lies in the relative proportion of coarser and finer granules, there being a larger proportion of coarser particles in the extra-fine grade and a larger proportion of finer crystals in the fruit-fine grade.

In Figure 6 photomicrographs of these eight sugars are shown, the magnification being held constant at about 20 diameters. A study of these photomicrographs proved very enlightening to the authors, and they are here given in the hope that they will prove equally helpful to others interested in this field.

In Figure 7 a similar photomicrograph of No. 10 brown sugar is also given and should prove interesting. This is the light-brown sugar most commonly sold to both domestic and bulk consumers.

Experience has shown that any grade of sugar will vary somewhat in granulation from batch to batch and between refineries. Experience also indicates that fruit-fine sugar will often approach extra-fine granulated sugar in granulation. If it is decided to use fruit-fine sugar as a standard ingredient of a baking test, it is obviously important to insure that variation from shipment to shipment be kept at a minimum. As a result of our investigations, it was decided that passing our cake sugar through a 30-mesh screen would eliminate much of the variability among different batches of cake sugar. Table IV shows the granula-

TABLE IV

STANDARDIZING EFFECT OF PASSING SUGAR
Through a 30-Mesh Screen

	Extra fine (standard)	Coarse batch fruit fine	Coarse batch fruit fine (screened)	Fruit fine (standard)
	%	%	%	%
On 35 mesh	8	6.9	2.0	3
On 48 mesh	25	23.0	24.2	18
On 65 mesh	30	33.3	35.0	35
On 100 mesh	25	26.2	27.6	29
Through 100 mesh	12	10.6	11.2	15

tion standard for extra-fine sugar and shows the actual granulation results obtained on a rather coarse shipment of fruit-fine sugar. This coarse shipment of fruit-fine sugar was passed through a 30-mesh

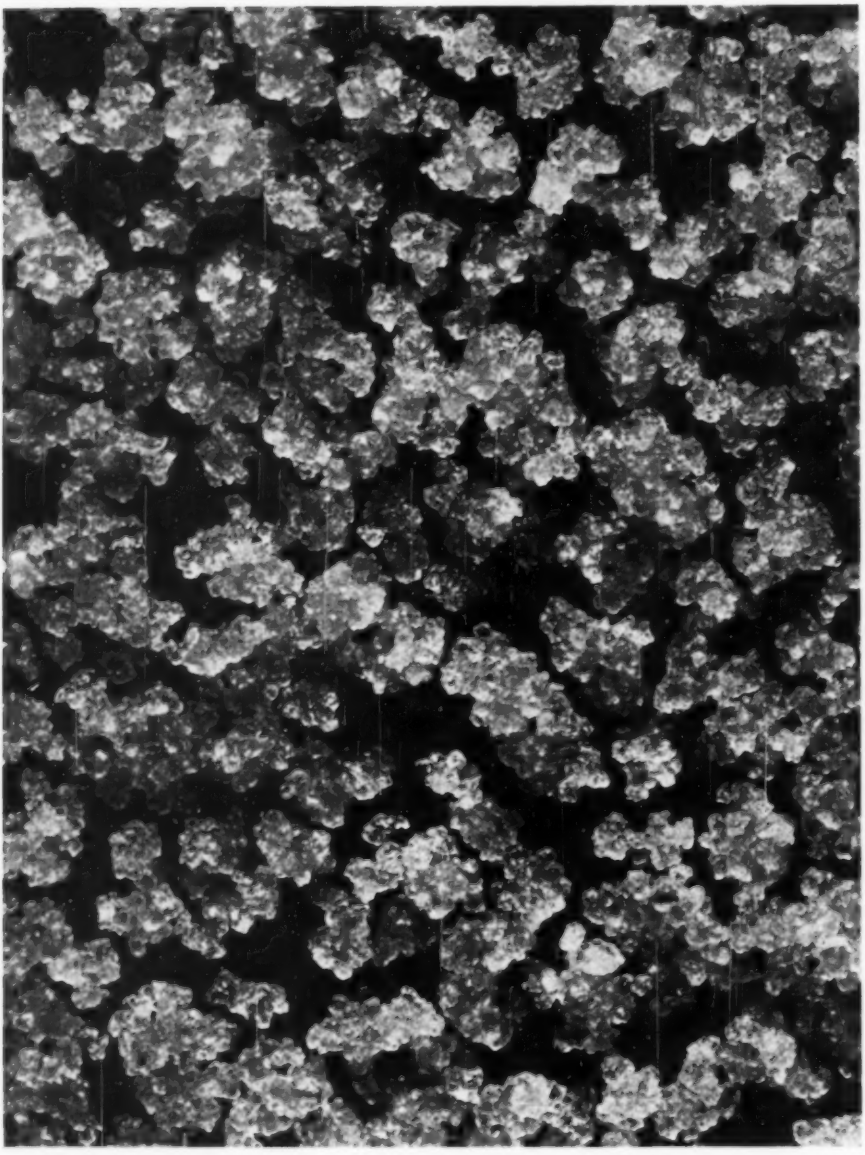


Figure 7. Photomicrograph of No. 10 brown sugar (×20).

screen and it is apparent that the granulation characteristics after screening approached the fruit-fine standard much more closely.

In order to show the effect of pre-screening sugar on cake results obtained under the standard pound-cake procedure, samples of extra-fine granulated and of fruit-fine granulated were tested before and after screening. The data are presented in Table V and show the

TABLE V

PRE-SCREENING SUGAR TO ELIMINATE VARIABILITY

Grade of sugar	Specific volume of preliminary cream	Specific volume of finished cream	Specific volume of dough	Loaf volume in c.c.
Extra-fine granulated (as received)	1.34	1.81	1.31	2714
Fruit-fine granulated (as received)	1.42	1.87	1.32	2765
Extra-fine granulated (screened)	1.38	1.85	1.3	2770
Fruit-fine granulated (screened)	1.42	1.87	1.33	2776

standardizing effect of this pre-screening operation. Incidentally, very little time is required to screen the sugar. If a 16- or 18-inch round screen is used, 10 pounds will pass through in less than one minute. The sugar which will not pass through should be discarded or used for some other purpose. The cakes obtained in the tests just described are shown in Figure 8. It would appear, therefore, that a pre-screening tends to eliminate variability due to sugar granulation.

CONDITIONING SHORTENING PRIOR TO USE

Another important factor was investigated which resulted in a much-improved control of the pound-cake test. Three shortenings were divided, each into three sub-samples. One set was conditioned at 50° F. for 100 hours and then conditioned at 70° F. for 100 hours. The second set was held at 70° F. for 200 hours and constituted the control. The third set was conditioned at 90° F. for 100 hours, and subsequently stored at 70° F. for 100 hours. The size of the sub-samples was such that the temperature of storage was reached in a very few hours after exposure. Two all-hydrogenated shortenings and one soft compound were selected for making this test. The pound-cake data are given in Table VI.

It is apparent from these data that previous storage conditions seriously affected the baking characteristics of these shortenings, regardless of the fact that all were well conditioned at 70° F. prior to testing. A baker, therefore, who stores shortening under very cold

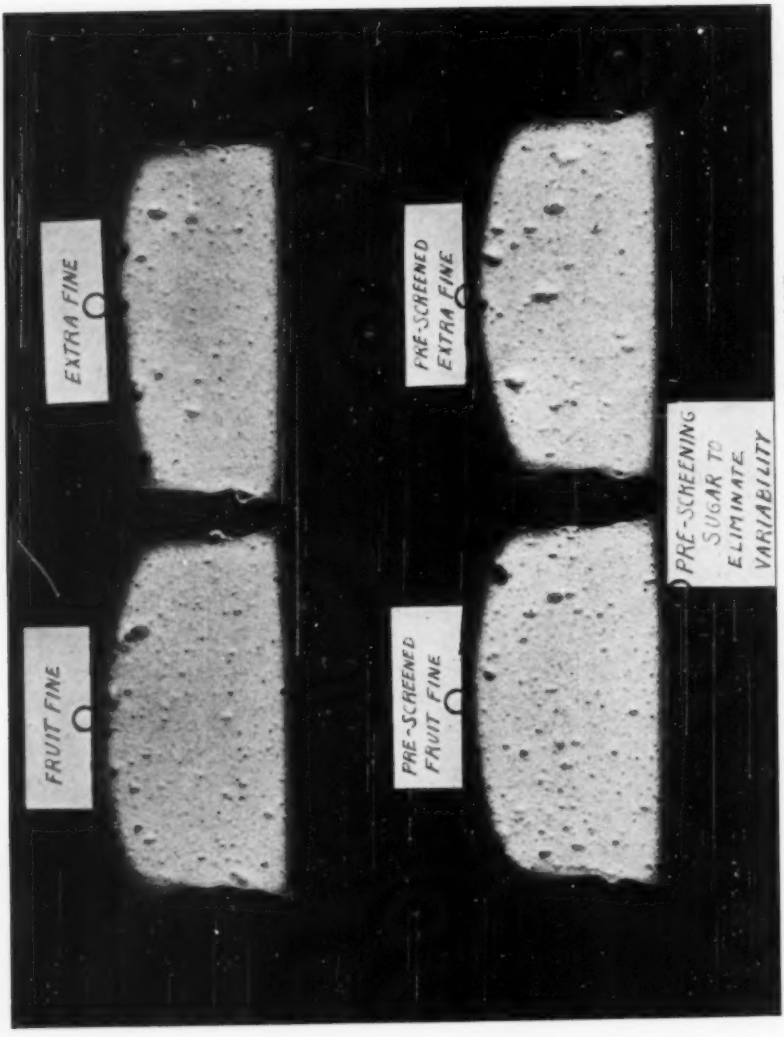


Figure 8. Effect of pre-screening sugar to eliminate variability.

TABLE VI

EFFECT OF PREVIOUS STORAGE TEMPERATURE ON BAKING VALUE OF SHORTENING

Temperature conditions to which shortenings were subjected	Stored at 50° F. for 100 hours, then stored at 70° F. for 100 hours			Stored at 70° F. for 200 hours			Stored at 90° F. for 100 hours, then stored at 70° F. for 100 hours		
Shortenings	Sp. vol. of cream	Sp. vol. of dough	Loaf volume in c.c.	Sp. vol. of cream	Sp. vol. of dough	Loaf volume in c.c.	Sp. vol. of cream	Sp. vol. of dough	Loaf volume in c.c.
All-hydrogenated shortening "A"	1.87	1.31	2708	1.87	1.32	2765	1.85	1.31	2689
All-hydrogenated shortening "B"	1.81	1.28	2709	1.85	1.31	2734	1.82	1.29	2647
Soft compound	1.79	1.28	2656	1.81	1.31	2609	1.76	1.24	2354

or very warm conditions cannot expect to obtain maximum results from shortening so abused. Warm storage conditions appear to exert a marked deleterious effect on soft-bodied shortenings. It is also apparent that some all-hydrogenated shortenings are affected more than others by storage conditions. The cakes resulting from these experiments are shown in Figure 9.

VARIABLE LIQUID

Another important feature in controlling the standard pound-cake test proved to be the variation in liquid necessary to keep the batter consistency constant. The effect of varying the liquid on the pound cakes obtained is shown for two shortenings in Table VII. It is thus apparent that the standard pound-cake test tends to bring out the liquid tolerance of various shortenings. The cakes resulting from these tests are shown in Figure 10.

TABLE VII

EFFECT OF LIQUID ON CAKE CHARACTERISTICS

	Shortening "A"			Shortening "B"		
	450 c.c.	500 c.c.	550 c.c.	450 c.c.	500 c.c.	550 c.c.
Specific volume of cream	1.87	1.88	1.86	1.98	1.99	1.99
Specific volume of dough	1.48	1.47	1.43	1.48	1.40	1.38
Loaf volume in c.c.	2995	2962	2889	2929	2867	2765

EFFECT OF HUMIDITY

Numerous references may be found in the literature on the effect of altitude on the cake-making processes. Recently, Barmore (1936) has presented some interesting data in this field. Such studies as those now being carried on at Colorado State College should prove

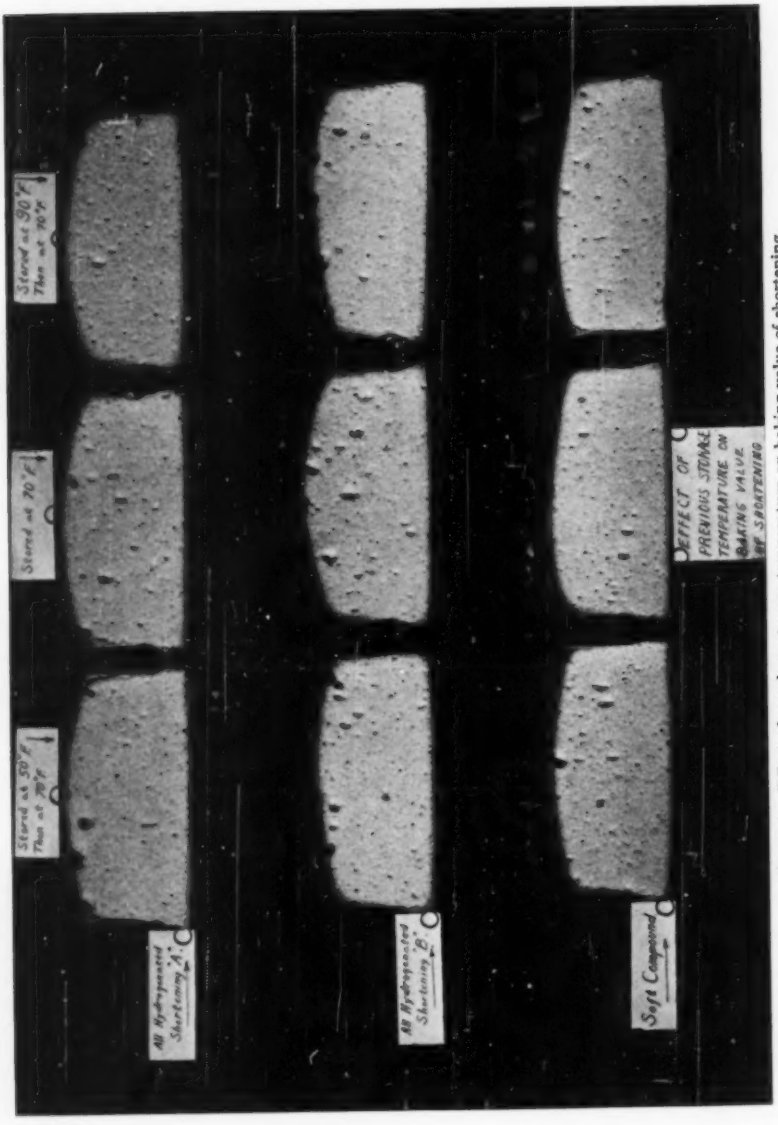


Figure 9. Effect of previous storage temperature on baking value of shortening.

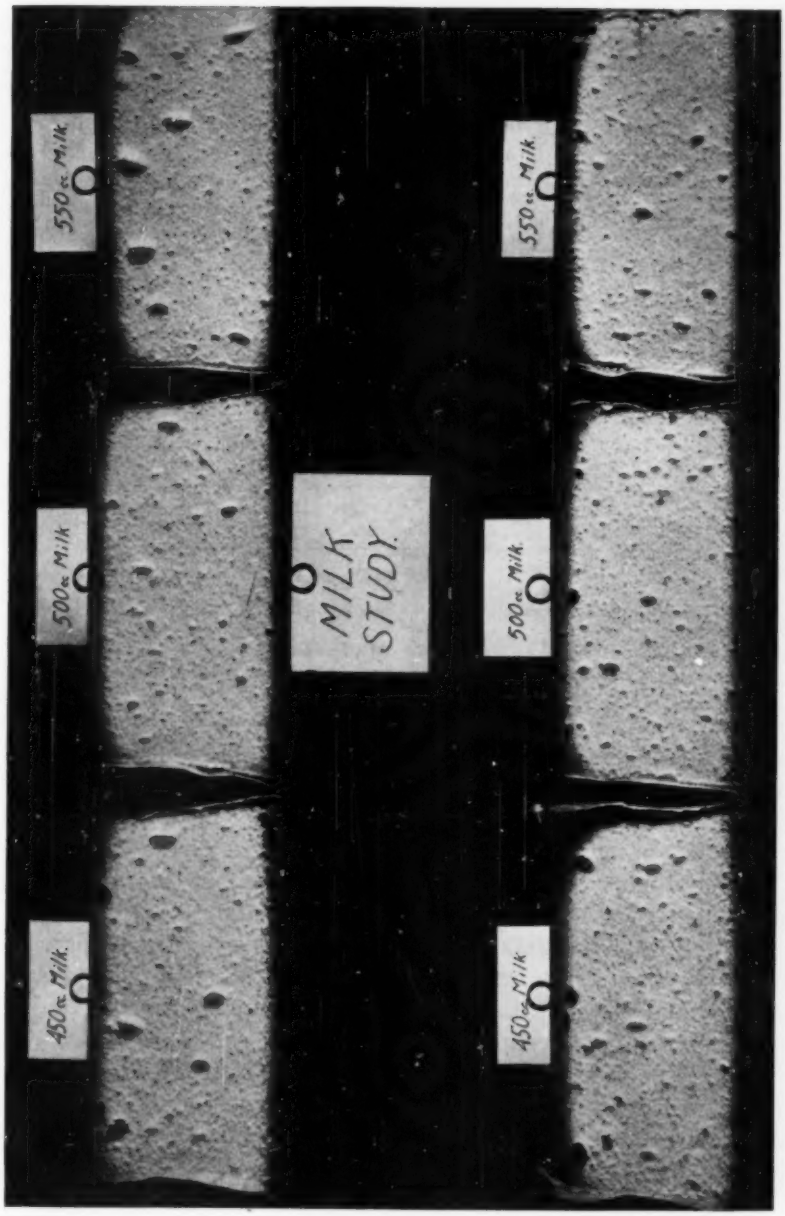


Figure 10. Effect of variation in amount of milk on the standard pound-cake test.

very helpful to those interested in baking at higher altitudes. Another environmental factor seems to play its part in cake making. Our Research Bakery being completely air-conditioned, it was possible for us to obtain some data on the effect of relative humidity on the cake-making procedure. Cakes were baked on the same day, with the same ingredients and within three hours of one another. The room temperature varied only one degree, but the humidity was caused to vary from 25% (a relatively dry condition) to 65% (a humid condition). So far as we could ascertain, no other factors were permitted to vary. The resulting data are given in Table VIII. Two different grades of sugar were tested under each condition: namely, fruit-fine and fruit-powdered.

TABLE VIII

EFFECT OF HUMIDITY ON CAKE CHARACTERISTICS

Humidity	25% relative humidity at 76° F.		65% relative humidity at 77° F.	
Type of sugar	Fruit fine	Fruit powdered	Fruit fine	Fruit powdered
Specific volume of preliminary cream before eggs are added	1.44	1.51	1.44	1.51
Specific volume of finished cream	1.78	1.84	1.81	1.84
Specific volume of dough	1.30	1.33	1.31	1.33
Loaf volume in c.c.	2786	2805	2725	2745

It is apparent that the effect of sugar granulation tends to be of lesser magnitude if the humidity is high. Experience in making pound-cake tests in different localities (where the humidity naturally varied over a rather wide range) has led us to feel that higher humidities do tend to give lower cake volumes. Possibly, this explains an old saying often heard when bakers of the old school discussed their art: "Cake volumes are usually low in muggy and rainy weather."

Data such as those shown in Table VIII are exceedingly difficult to obtain without being accompanied with another variable. Possibly the staff at Colorado State College may some day throw more light on this interesting question.

It is recognized that there are a number of other factors involved in standardizing a cake-making test—the effect of eggs, flour, mixing machines, mixing times and temperatures, oven procedure and even the measurement of cake volumes. It could not be within the scope of this paper to include a discussion of all these factors. It is hoped, however, that the material which has been presented will be helpful to others whose problem parallels ours.

Summary

A simple, speedy and accurate method is recommended for measuring the lightness of the creamed mass and finished cake batters.

A cake test based on a relatively lean pound cake containing no leavening agent is recommended for testing such cake ingredients as shortening.

The granulation of sugar is a very important factor and variation in particle size may be kept at a minimum by pre-screening the cake sugar.

The effect of previous storage conditions on the baking value of shortening has been discussed. Storing shortening in a cold or in a hot environment is not recommended. Moderate storage temperature (70° to 75° F.) is recommended for shortening.

The batter consistency should be kept constant. To accomplish this, it is usually necessary to vary the amount of liquid from season to season.

There is some indication that humid conditions in the laboratory impair the volume of cakes.

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THE EMULSION-FOAM PRODUCED BY AGITATING BUTTER, SUGAR, AND EGG: A METHOD FOR TESTING THE STABILITY OF THE EMULSION AND THE EFFECT OF THE CONDITIONING TEMPERATURE OF THE FAT [1]

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Washington, D. C.

(Received for publication August 3, 1937)

In making fatty emulsions for cake batter the usual procedure in bakeries is to cream the fat and sugar and then to add the egg slowly. The agitation is continued for some time after all of the egg has been added. During this procedure, as will be shown, a water-in-oil emulsion and an air-in-oil foam are formed in the agitated mixture, consisting of fat globules, water droplets, air bubbles, and sugar crystals (Figures 1 to 7). Stability or persistency of the emulsion when the flour, milk, and other ingredients of the batter are added is very important.

The stability of the emulsion has to do with its ability to resist breaking or the coalescence of the water droplets and the separation of the internal phase into layers. Most emulsions are stabilized by the presence of another disperse phase, preferably a colloid which shows marked affinity for either the oil or the water. An emulsion breaks whenever the hydrophyllic colloid which holds the aqueous disperse medium is either diluted beyond the point where it can take up the added liquid, or is so influenced by external conditions that its original capacity for holding the dispersion medium is sufficiently reduced.

The breaking of the emulsion in fat-sugar-egg mixtures is known to the baker as "curdling." Prevention of breaking or curdling is one of the major problems in cake making. Although the term curdling has a very definite meaning, its causes and the state or the condition that prevails within the emulsion are not very well understood, and previous to 1930, when this work was begun, there was no method in use for measuring the stability of emulsions of this type. There are many references to curdling in the literature. Those by Bryant (1925) and Glabau (1928) are among the more significant ones.

[1] A paper on the effect of the conditioning temperature of fat was presented at the annual meeting, May 1931, and the method for testing the stability of the emulsion at the annual meeting, May 1932.

Selection, Preparation, and Storage of Materials

Butter:—The butter was made by the sweet cream process at the Government creamery at Grove City, Pennsylvania. It was shipped to Washington, placed in storage at − 14° C., and held at that temperature for six weeks before it was used in the investigation. Four samples were used in the investigation.

Butter-oil:—The butter-oil was made from a part of butter sample No. 2. The butter was melted by heating to not higher than 55° C., then the water, salt, and curd were removed by decantation and filtration. The butter-oil was placed in storage at − 14° C. while hot to prevent crystallization. No effort was made to ascertain the best method of preparation of butter-oil which would give the best creaming results, but precautions were taken to keep the product uniform except for the variants under consideration in the problem.

Hydrogenated vegetable fat:—Sufficient hydrogenated fat for the entire experiment was purchased and held in a cabinet maintained at 20° C.

Sugar:—Fruit granulated sugar was used. One day previous to use the sugar was weighed and placed in cabinets maintained at the same temperature as the fat with which it was to be used.

Eggs: [2]—Selected eggs from the Government Experiment Station at Beltsville, Maryland were used. They were chilled by holding several hours at 5° C. before removing from the shell. The eggs were carefully examined for odor and appearance, then mixed, strained, weighed, and placed in jars. Ten grams of sugar were added to 100 g. of egg. The egg-sugar mixture was frozen and maintained at frozen temperatures by placing in storage at − 14° C. The eggs, too, were held for about six weeks before use. Fourteen hours before they were used they were placed in a constant temperature cabinet maintained at 5° C., and just before use they were weighed and warmed in a water bath to 22.5° C.

Formula and method of preparing the emulsions:—The following was the basic formula:

Fat	180 g.[3]
Sugar	400 g.
Egg	200 g.

The fat and sugar were placed in the 3½-quart bowl of the Hobart mixer and blended together by stirring with the flat paddle which was later used for agitation. At all times, other than in blending the fat and sugar, the medium speed of the Hobart mixer was used. When egg was used as a part of the ingredients it was added after the butter

[2] It is probable that slow changes take place in eggs, butter, and butter-oil while in storage.
[3] Butter contains 20% substances other than fat; because of this 200 g. were used instead of 180.

and sugar had been creamed to a definite specific gravity, or after the butter and sugar had been creamed for a definite length of time.

The experiments were made in a room maintained at 22.5° C. Two stops of 30 seconds each were made near the beginning of the agitation, during which time the mixture was removed from the sides of the bowl and the paddle. When specific gravity determinations were made the mixer was stopped for 120 seconds. Each time specific gravity determinations were made the mixture was removed from the paddle and the sides of the bowl. Specific gravity determinations, which are regarded as a measure of the lightness of the foam, were made by weighing a known volume of the mixture.

In this paper the temperature adjustment of the fats just prior to use is referred to as the conditioning of the fats and is the temperature of the fat as it goes to the mixer.

Observations on Form or Structure

A study was made of mixture of butter-sugar-egg to determine the type of emulsion by the internal phase method (Palmer, 1926), by Briggs drop dilution method (Newman, 1914) and by the indicator method (Robertson, 1910). All three tests gave positive results for the water-in-oil type of emulsion.

Microscopic examinations:—Changes or differences in the structure when butter is creamed with sugar, and this mixture emulsified with egg, are illustrated by means of photomicrographs.

Figure 1 is a photomicrograph of butter. Fat is the continuous phase. Fat globules, air bubbles, and water droplets form the discontinuous phases.

Figure 2 is a photomicrograph of creamed butter and sugar. The large object is a sugar crystal, the small bubbles with the dark rings are air, and the other small droplets are water. Fat globules cannot be distinguished by the author; however, it is probable that some of these drops as viewed under the microscope are fat. There are more air bubbles in the mixture shown in Figure 2 than there are in the photomicrograph of butter (Figure 1), and the water droplets are larger in size.

When egg is added to the creamed butter and sugar, the water-in-oil emulsion is further modified and more air is incorporated. Figure 3 is a photomicrograph of a butter-sugar-egg mixture. It was found more satisfactory to remove the sugar crystals during the preparation of the slide because of the difficulty in having the preparation thin enough to show the emulsion-foam phase.

Figure 4 is a photomicrograph of an emulsion in which the water droplets are much larger than in Figure 3. In making this mixture

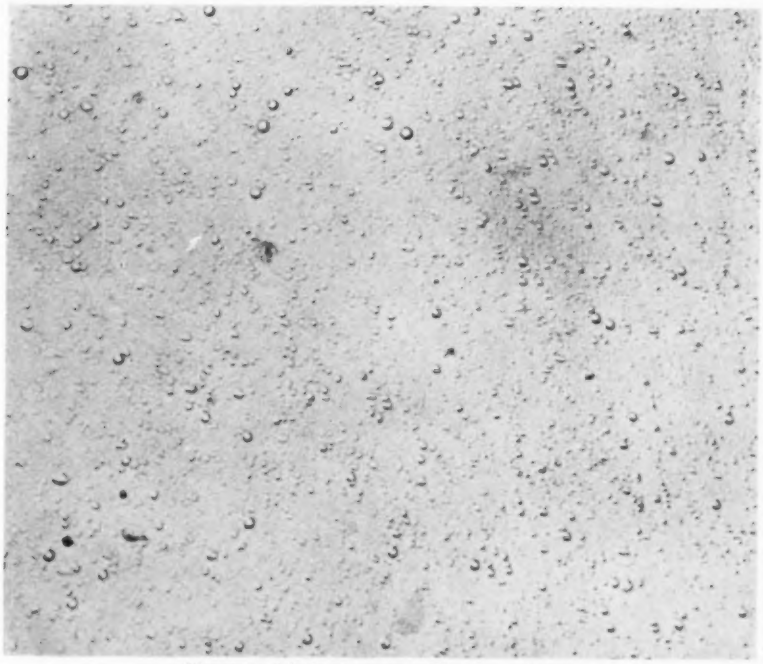

Figure 1. Photomicrograph of butter. × 200.

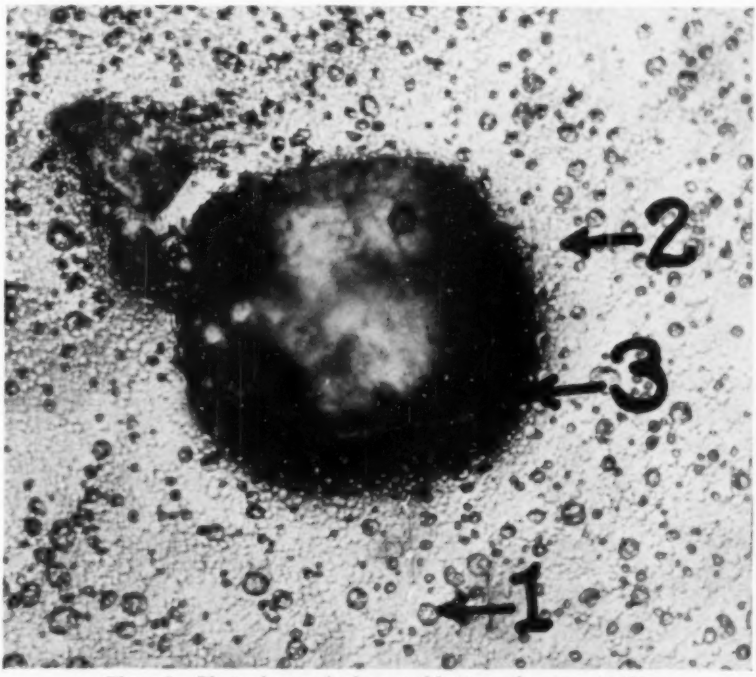

Figure 2. Photomicrograph of creamed butter and sugar. × 200.
(1) Air bubbles. (2) Water droplets. (3) Sugar crystals.

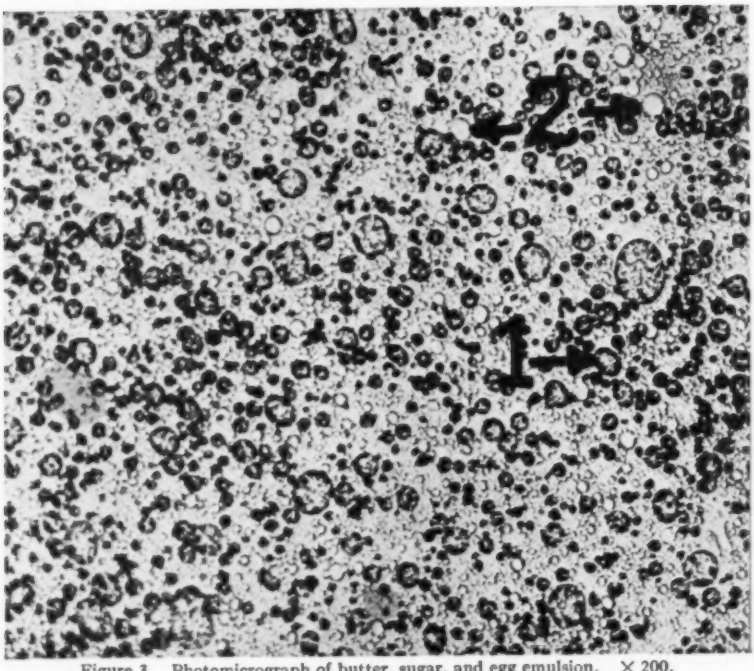

Figure 3. Photomicrograph of butter, sugar, and egg emulsion. × 200.
(1) Air bubbles. (2) Water droplets.

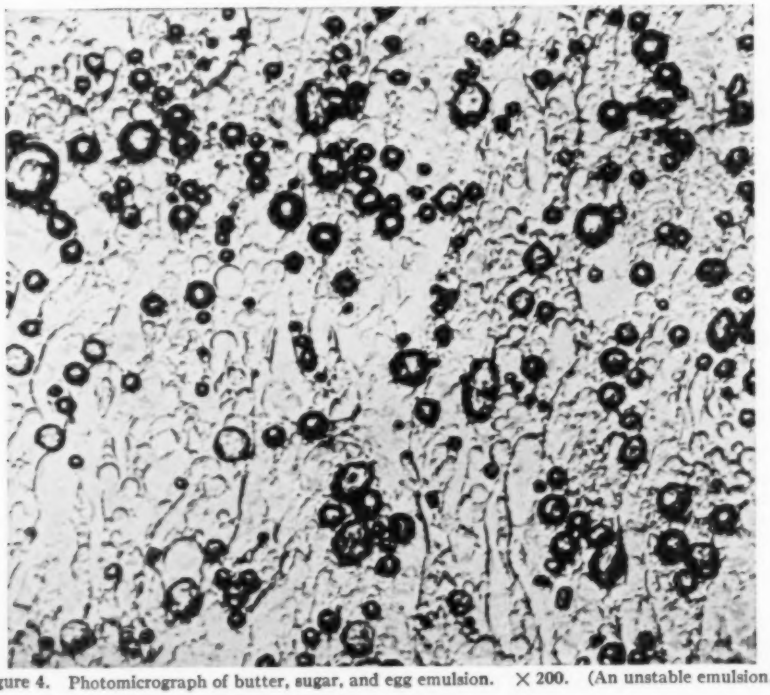

Figure 4. Photomicrograph of butter, sugar, and egg emulsion. × 200. (An unstable emulsion.)

all of the egg was added at one time and the mixture thereafter agitated for 15 minutes. The emulsion is much less stable than the emulsion used for Figure 3 where the egg was added gradually over a period of 3.75 minutes and the agitation continued 11.25 minutes after all of the egg was added. It will be observed that some of the larger water droplets were broken during the preparation of the slide, and that the slide shows the direction the spatula was drawn in preparing the slide.

Stable emulsions are frequently found in which water droplets are so small that only a very few are visible when examined under the microscope. Figure 5 is representative of this type of emulsion.

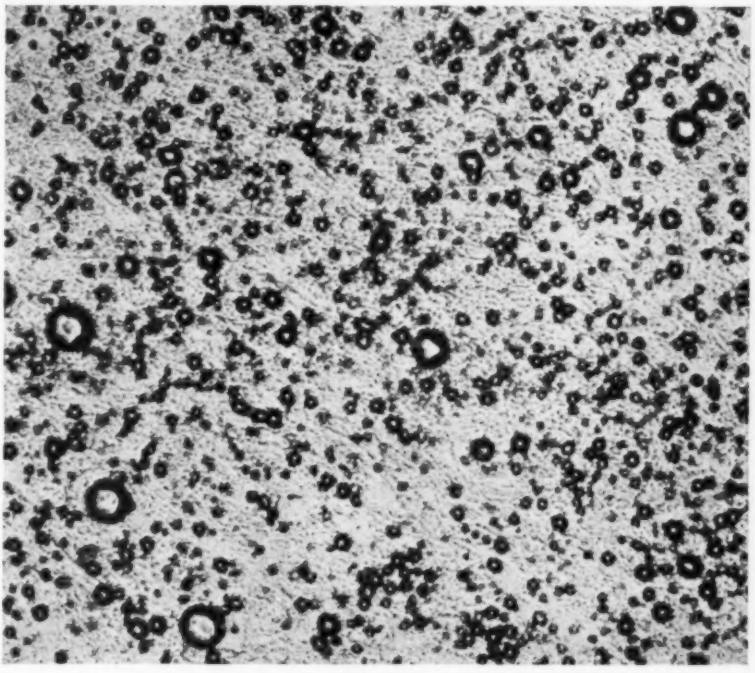

Figure 5. Photomicrograph of butter, sugar, and egg emulsion. × 200. (A stable emulsion.)

When emulsions of these three types are placed in containers and kept for some time much of the aqueous phase will separate from the type represented in Figure 4. There will be almost no separation from that represented in Figure 5.

Identification of sugar crystals, water droplets, and bubbles:— Figure 6 is a photomicrograph of creamed hydrogenated fat and sugar. The identity of the air bubbles as distinguished from the water droplets in the creamed butter and sugar may be established by means of this

photograph. Hydrogenated fat does not contain water; therefore, the bubbles with the heavy dark rings are air. The difference in refractive index between air and fat is greater than that between water and fat, which in part accounts for the ring which forms the outer surface of the water droplets being darker than the rings which form the outer surface of the air bubbles. Emulsions which have large drops of water which are broken during preparation of the slide further establish the identity of the water as the water may be seen to flow when examined under the microscope. The crystalline material, the sugar, was detected by examining it in parallel polarized light (cross nichols).

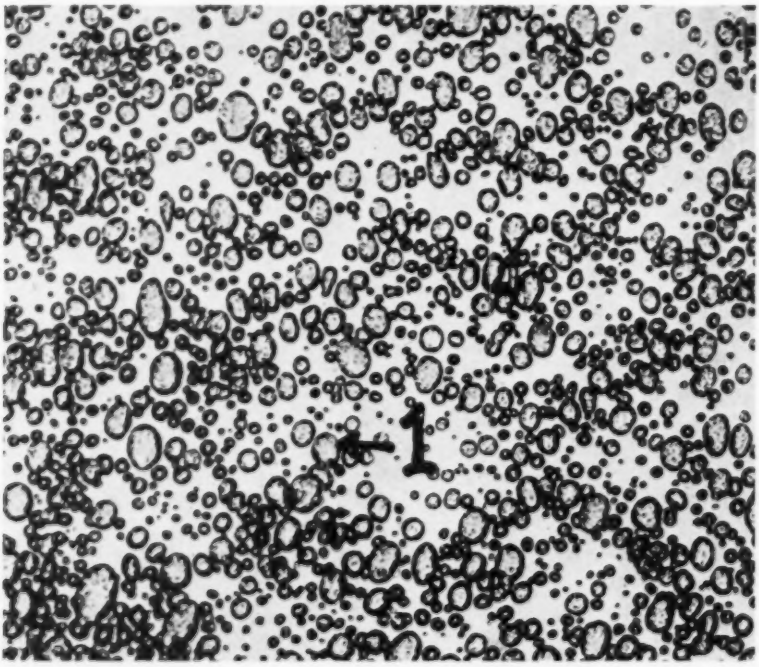

Figure 6. Photomicrograph of creamed hydrogenated fat and sugar. × 200. (1) Air bubble. Left, egg added over a period of 3.75 minutes. Right, egg added over a period of 1.5 minutes.

Stability and Its Measurements

In this laboratory a number of methods for determining stability have been tried, including the use of a pentrometer, the measurement of the electrical energy required during the mixing, the measurement of the conductivity of the emulsion foam, the measurement of ease of centrifugal separation, and the use of viscosimeters. Two modifications of the Ostwald viscosimeter were tried, one in which the mixture was drawn through by suction, and another in which the mixture was

forced through by pressure. It was not practical to use some of these methods because of the air being present in the form of a foam. The McMichael viscosimeter, loaned by the Bureau of Agricultural Economics, was found to be quite satisfactory, and was used in some work reported in a subsequent paper of this series.

Settling Test

A method in which the emulsion was allowed to stand in containers and measurements made on the aqueous phase which separates from the oil was found to be very satisfactory. The stability of an emulsion is dependent upon the physical state and strength of the lamellae. The rupture of these membranes, as was mentioned previously, results in the coalescence of the water droplets and subsequent settling of the aqueous phase to form a layer. The amount of aqueous phase which separates under definite conditions may therefore be used as a relative measure of the stability of the emulsion.

Selection of containers:—Test tubes 150 mm. × 26 mm. were selected for containers. They were of a size that may be easily filled and hold a suitable amount of material. It is essential that uniform containers be used. The tubes were standardized by placing 10 c.c. of water in each and measuring the height from the lower part of the container with a ruler. One millimeter was used as the maximum variation.

Filling the tubes:—The tubes were first weighed and then filled. The technique of filling the tube consists in conveying a portion to the tube by means of a case knife, the first portion being carefully worked to the bottom of the tube, using care that there are no air spaces in the bottom of the tube. When a portion does not work in readily it must be discarded as excessive working modifies its structure. Thirty five grams was the amount selected to be used in each test.

Storage during breaking of the emulsion:—Since fat is sensitive to temperature changes, it is necessary to use temperature control during the time separation takes place. It was found necessary to establish the most suitable temperature for each mixture. This was found to vary from 24° to 31° C., depending on the fat used in the mixture.

Securing the data:—The amount of liquid which separates and settles to the bottom of the tube is regarded as a measure of the ease with which the emulsion breaks, or its lack of stability. The volume of the aqueous phase was measured by comparison with other tubes containing measured quantities of liquid paraffin. Graduated cylinders would be very convenient. Since results obtained by this method are comparative, it is desirable to run a control for each series of tests as the basis of comparison of readings. Possibly the time required

for the separation of a definite volume of aqueous phase would also be a satisfactory measure of stability.

The use of the stability test is illustrated by an experiment on the effect of rate of addition of egg.

Effect of rate of addition of egg:—The effect of adding egg too rapidly is known to the baker as one of the chief causes of curdling. A study of this was made by shortening the interval of time between additions of egg. The regular method in use in this laboratory consists in creaming the butter and sugar to a desired specific gravity, then adding 200 grams of egg in 16 additions at intervals of 0.25 minute. As a variant on this procedure egg was added at intervals of 0.10 minute. Specific gravity and stability were determined on samples taken at the end of 5, 10, and 15 minutes' agitation, these intervals being reckoned from the time the addition of egg was begun. The results are recorded in Table I. Photographs of the tubes are shown in Figure 7. It will be noted that more air was occluded in the emulsion to which the egg was added more rapidly and that the emulsion was much less stable.

The effect of rate of addition of egg has been studied on nine different samples of butter. The results on all nine were similar to those recorded in Table I.

TABLE I

THE RELATION OF THE RATE OF ADDITION OF EGG TO THE SPECIFIC GRAVITY AND STABILITY OF THE EMULSION

Experiment number	Specific gravity of emulsion (water = 1.0)				Stability of emulsion		
					Aqueous separation after settling 3 days		
	Time interval of subsequent addition of egg	1 minute after all the egg is added	10 minutes from first addition of egg	15 minutes from first addition of egg	Tube filled 1 minute after all the egg is added	Tube filled 10 minutes from first addition of egg	Tube filled 15 minutes from first addition of egg
	Minutes	%	%	%	*C.c.*	*C.c.*	*C.c.*
1	0.25	0.81	0.80	0.77	4.5	1.7	2.0
2	0.10	0.72	0.67	0.69	13.0	6.0	3.0

The stability test has been used in several other problems and found to be satisfactory. In most of these investigations the only test made was on the mixture after 15 minutes' agitation. When only one test is made it is much easier to arrange for publication than when more than one is desired as in the illustration used.

Effects of Conditioning Temperature of the Fat

Fats which are semi-solid at ordinary working temperatures are more satisfactory for cake-making purposes than liquid oils or solid

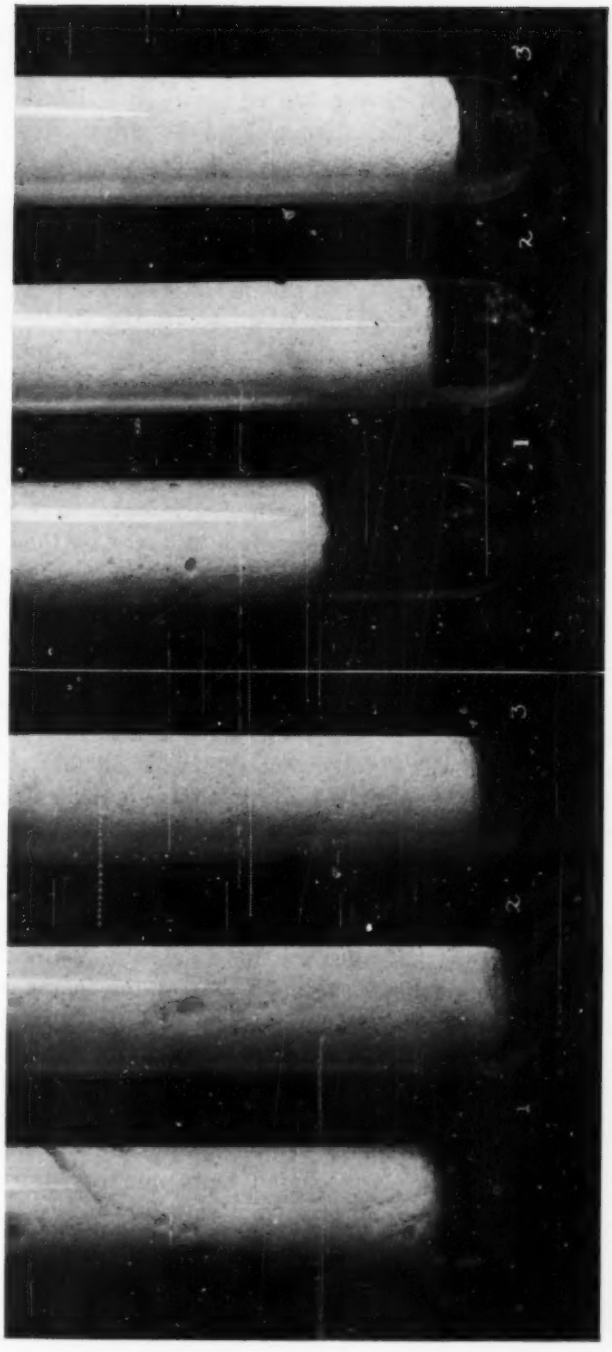

Figure 7. Effect of rate of adding egg on stability of the emulsion (after 3 days settling). No. 1, one minute after all the egg was added; No. 2, ten minutes after first addition of egg; No. 3, fifteen minutes after first addition of egg.

fats. Plasticity is the determining factor; it is in part dependent upon the degree of saturation and the melting points of the fatty acids of the fat. Cottonseed oil, peanut oil, and beef tallow are not as satisfactory as butter and lard; they lack the desired plasticity. Butter does not have a sharp melting point but changes gradually from the solid to the liquid state, or vice versa, over a range of several degrees of temperature, hence temperature is a very important factor.

Hydrogenated fats have been used with considerable success in cake batters; for this reason a hydrogenated fat was selected for study along with butter and butter-oil in this investigation.

The importance of temperature is shown by the studies made by investigators (1927) in the laboratories of Proctor and Gamble, and by Glabau (1930). In the former studies it was shown that when the air incorporated in creaming is the only leavening agent the cake volume is directly proportional to the creaming volume, and that the temperature was an important factor. Glabau studied the effects of temperature on the score of the finished cake which was found to be a function of the specific gravity of the cake mixture as affected by the incorporation of air.

The effect of temperature of the fat on the creaming properties of fat and sugar:—Samples of butter, butter-oil, and hydrogenated fat that had been stored for three days at temperatures approximating 19°, 21°, 23°, and 25° C. were creamed with sugar. Specific gravity determinations were made at frequent intervals; the results are plotted in Figures 8 and 9. It will be observed that with all fats the specific gravity of the mixture conditioned at 25° C. was less than that of the mixture conditioned at 23° C. Similar differences were shown between the effects of storage at 23° and 21° C. and between effects of storage at 21° and 19° C., indicating that in the temperature range covered the higher the storage temperature of the fat, the more air incorporated in the emulsion. There was a much greater difference in specific gravity of the foams containing butter than in that of the foams containing butter-oil and hydrogenated fat.

Different samples of butter were found to vary in their creaming properties. Since our interest is primarily that of butter, the results on three different samples are included in the report. It will be observed that for equal times of creaming and similar conditioning temperatures, butter No. 16 occluded more air than butter No. 6 and that butter No. 6 showed a greater variation in specific gravity at the two warmer temperatures studied, namely 23° and 25° C.

In making of cakes it is necessary to cream the butter and sugar before adding the egg. In 1930 when this investigation was started it was customary in industrial laboratories to cream hydrogenated

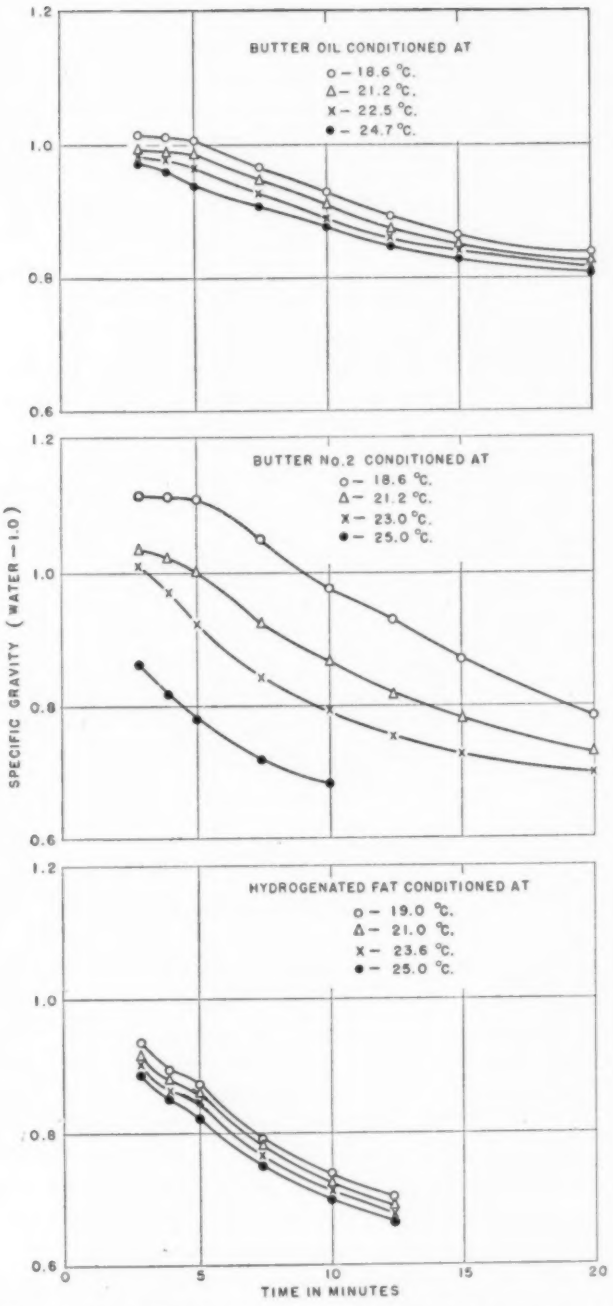

Figure 8. Effect of length of time of creaming butter-oil, butter, and hydrogenated fat on specific gravity when the fats have been conditioned at different temperatures.

fat and sugar a definite length of time before adding egg. Different samples of butter vary much more than different samples of hydrogenated fat in the amount of air which they incorporate when creamed with sugar for a given length of time. Because of the greater variation in creaming properties of different samples of butter, specific gravity of the creamed butter and sugar was used as a means of deciding upon the time to add the egg in a part of the work included in the report.

The effect of temperature of fat on the specific gravity and stability of the fat, sugar, and egg emulsions:—In one investigation samples of butter-oil, hydrogenated fat, and butter No. 2 that had been conditioned at temperatures approximating 19°, 21°, 23°, and 25° C. were creamed for five minutes with sugar; egg was added gradually over the next five minutes of agitation and agitation continued 25 minutes

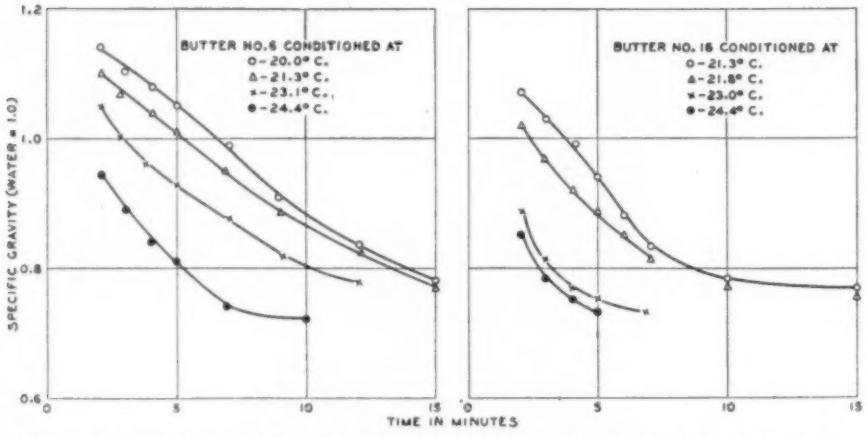

Figure 9. Effect of length of time of creaming butter and sugar on specific gravity when the butter is conditioned at different temperatures.

longer. Specific gravity determinations made at regular intervals are plotted in Figure 10.

When the emulsion formed by adding egg to the creamed butter and sugar, all three fats tend to give an emulsion of less specific gravity with the conditioning temperature of the fat at progressively higher temperatures. There was a greater range in specific gravity for the emulsions containing butter conditioned at these four temperatures than there was for the emulsion containing butter-oil. The emulsion containing hydrogenated fat gave the smallest variation as in the previous experiments in which no egg was added.

When butter No. 6 and No. 16 were used the butter and sugar were creamed until the mixture had a specific gravity of 0.93 before the egg was added. Although the same amount of air was occluded, it is quite

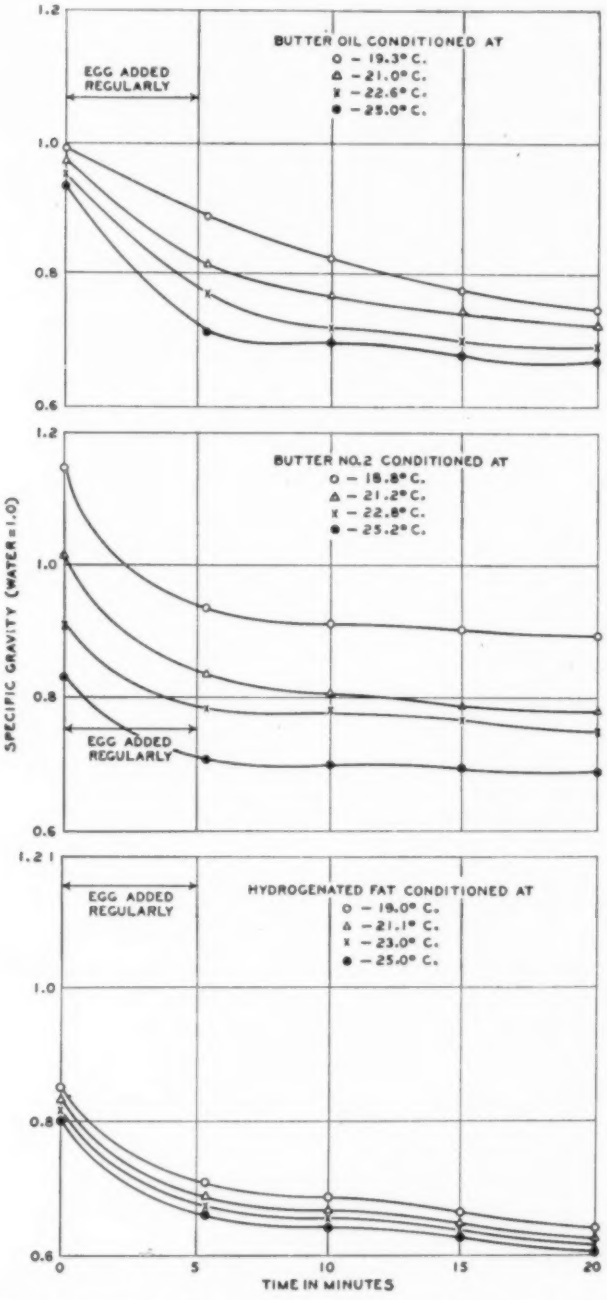

Figure 10. Effect of agitating fat, sugar, and egg on specific gravity when the fats are conditioned at different temperatures.

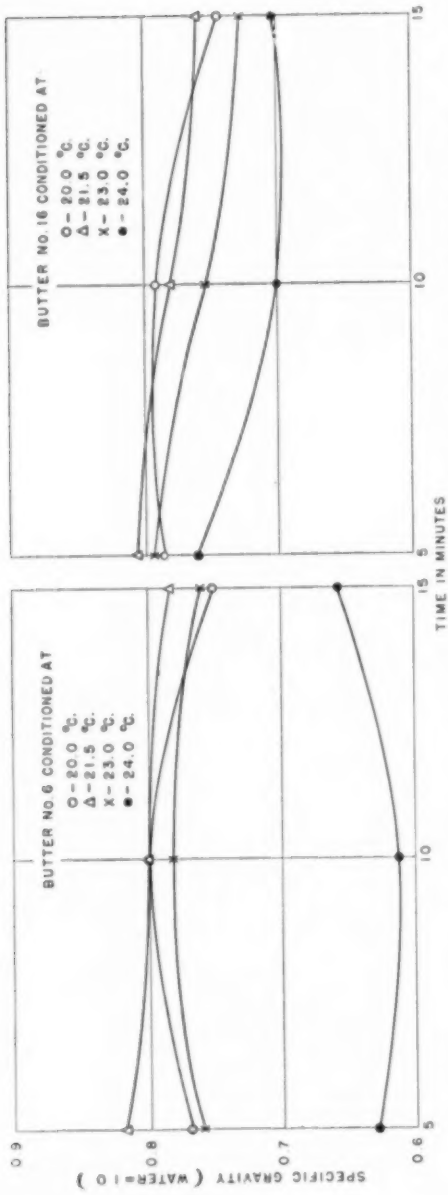

Figure 11. Effect of conditioning temperature of butter on specific gravity when butter, sugar, and egg are agitated.

certain that the emulsion foam varied in other respects as a result of this difference in time of creaming. Specific gravity determinations were made at five-minute intervals starting five minutes after the first addition of egg. The data are recorded in Figure 11. It will be observed that the specific gravity curves do not continue in the same uniform manner as they did in Figure 10, when the egg was added at the end of a five-minute creaming period.

During the past several years the author has had a rather extensive experience with specific gravity curves obtained by agitating butter, sugar, and egg. Unlike the curves obtained from the data secured by agitating butter and sugar, they show considerable variation and are difficult to interpret. It seems that the more stable emulsions are formed when the mixtures show a slight decrease in specific gravity with time of agitation. Emulsions with specific gravity less than 0.75 are usually unstable.

The emulsions were tested for stability by means of the settling test. The data are recorded in Table II. The emulsions made from

TABLE II

EFFECT OF CONDITIONING TEMPERATURE ON THE STABILITY OF THE EMULSION FORMED BY AGITATING BUTTER, SUGAR, AND EGG

Butter No. 6		Butter No. 16	
Temperature of butter	Stability (separation in cubic centimeters from 35 g. upon standing 3 days at 24° C.)	Temperature of butter	Stability (separation in cubic centimeters from 35 g. upon standing 3 days at 24° C.)
° C.	C.c.	° C.	C.c.
19.5	0.2		
21.5	0.0	21.8	0.5
23.0	0.3	23.0	2.0
24.0	0.8	24.4	2.5

butters conditioned at 23° and over, or 21° C. and under, were less stable than those made from butters conditioned between 21° and 23° C. Hilditch and Sleighthome (1930) and others have shown that different samples of butter differ in their fatty acid content. Since they differ in their fatty acid content they will very probably differ in their optimum creaming temperature. A close approach to the optimum creaming temperature was not attempted for these two samples as it would be of value for these two particular butters only. A study of plasticity of butter would be of value in further investigations of this nature.

Summary

One of the well established facts in the baking industry is that cakes made from batters which break are less satisfactory than when made from batters which do not break.

Sugar crystals, water droplets, and air bubbles in butter-sugar-egg emulsions were identified by microscopical examination. It was proved that butter, sugar, and egg mixtures after agitation are water-in-oil emulsion and air-in-oil foams.

A settling test for determining the relative stability of the fatty emulsions was devised. This method will give a means of studying the causes and effect of lack of stability of the emulsion of cake batters.

An emulsion formed when the egg is added slowly is more stable than when the egg is added rapidly.

Effect of variation in the conditioning temperature on creaming and emulsifying properties of butter, butter-oil, and hydrogenated fat was studied. In the range of 19° to 25° C. the conditioning of fat at the higher temperature causes the fat-sugar foam and the fat-sugar-egg emulsion to incorporate more air than conditioning at the lower temperature. Emulsions containing butter incorporated less air than those containing butter-oil, and those containing butter-oil less than those containing hydrogenated fat.

The temperature of storage that caused butter to give the most stable emulsion when mixed with sugar and egg was 22° C. (+ or −) for the samples of butter used in this investigation.

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THE EFFECT OF FORMULA AND PROCEDURE VARIABLES UPON CAKE QUALITY

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(Read at the Annual Meeting, June 1936)

The Chairman of the Committee on Cake Baking and Self-Rising Flours at the annual meeting of the A. A. C. C. in 1935 advocated the presentation, to the membership or to individuals who were interested, of photographs of cakes which showed clearly the effect of unbalanced formulas, manipulation, or baking quality of the flour in test.

The chairman of that committee for the current year asked that we present to this convention the effect of several formula and procedure variables upon cake quality using the method of preparation which had been developed in our laboratory. He later suggested that we include a comparison of the effect of these formula variables upon cakes prepared by the A. A. C. C. method in one series with those prepared by our method in another series using two flours of different baking quality as subjects.

Accordingly we are reporting on (1) the effect of formula and procedure variables upon the quality of cakes prepared by our laboratory method, and (2) a comparison of the effect of formula variables using the A. A. C. C. method and our laboratory method.

The essential difference between the two formulas is in the egg content. The A. A. C. C. formula calls for 12 g. of dried egg albumen per 260 g. of flour. The laboratory method calls for 130 g. of whole egg per 260 g. of flour.

Cream of tartar and sodium bicarbonate, the official leavener of the Association, was used in this study.

Series I

A series of bakings was made for record by means of photographs of cake characteristics and the effect of certain formula and procedure variables upon these characteristics. The variables in this study were:

Formula		Procedure	
1. Sugar	[1]	1. Mixing time	3 min.
	+25%		6 min.[1]
	−25%		9 min.
2. Fat	[1]	2. Quantity of batter	250 g.
	+25%		300 g.[1]
	−25%		350 g.
3. Liquid	[1]	3. Baking temperature	325° F.
	+25%		375° F.[1]
	−25%		425° F.
4. Baking powder	[1]		
	+50%		
	−50%		

[1] Control.

Preliminary bakings had established these changes as being within the limits of acceptable cake quality and as sufficient to show effect upon grain, texture, general appearance and volume of the cakes.

Our laboratory formula and procedure for plain whole-egg cake, as used for the controls, are given below.

Plain whole-egg cake	Hobart mixer—3-quart bowl
100 g. shortening	Creamed 1 minute medium speed
200 g. fine granulated sugar	Sift dry ingredients together
200 g. cake flour	
20 g. whole milk powder	Place in mixing bowl. Add water
6 g. salt	Mix 3 minutes at medium speed
10 g. cream tartar baking powder	Scrape bowl and add
100 g. water	
100 g. whole egg	Mix 3 minutes at medium speed
30 g. water	
	Pan 300 g. of batter in 7-inch round layer pans. Bake 25 minutes at 375° F. in Despatch Rotary Electric Oven

Formula Variables

The following general conclusions may be drawn regarding the effect of formula variables upon cake quality.

Sugar	Increase	Grain —coarser, less uniform than control Volume—slightly larger Texture—more tender
	Decrease	Grain —finer than control Volume—smaller Texture—slightly tough and tight
Fat	Increase	Grain —same as control Volume—slightly smaller Texture—greasy

	Decrease	Grain —same or slightly coarser than control Volume—larger Texture—tight, harsh
Liquid	Increase	Grain —finer than control Volume—smaller Texture—moist and tender
	Decrease	Grain —coarser and less uniform than control Volume—larger Texture—harsh, dry texture
Baking powder	Increase	Grain —coarser than control but uniform Volume—larger Texture—slightly harsh, tender
Baking powder	Decrease	Grain —fine, close, not as distinct as control Volume—smaller Texture—tight and slightly soggy

The cakes in which the sugar was increased, those in which the baking powder was increased, and those in which the liquid was decreased, have some similar characteristics such as coarse grain, large volume, and flat contour of crust. They are dissimilar in that the cakes with the increased baking powder are more tender and much more desirable than the cakes with decreased liquid.

Procedure Variables

The following general conclusions may be drawn regarding the effect of procedure variables:

Mixing time. Three minutes' mixing is not sufficient, and 9 minutes' is too much for the best cake quality. Insufficient mixing gives a coarse, slightly harsh cake, and over-mixing gives a close, slightly tough cake.

Quantity of batter. Two hundred and fifty grams of batter in a 7-inch round layer pan are insufficient. The volume of such cakes resembles underleavened cakes. The color and grain, however, are satisfactory. Three hundred and fifty grams of batter in a 7-inch layer pan are too much for best results; *i.e.*, a cake as light and of better grain and texture is produced with 300 g. of batter.

Baking temperature. A baking temperature of 325° F. is too low and 425° F. too high for desirable cake quality. The lower baking temperature, however, produced better, more consistent results than the high temperature. The long baking necessary at this temperature (325° F.) gives a drier cake than is desirable.

The weights, volumes and specific volumes of the finished cakes are as follows:

FORMULA VARIABLES

Sugar	Weight of cake	Volume	Specific volume
	G.	*C.c.*	
+25%	252.4	839	3.32
Control	254.8	842	3.30
−25%	254.0	710	2.79
Fat			
+25%	253.0	815	3.23
Control	254.8	842	3.30
−25%	257.4	870	3.38
Liquid			
+25%	250.9	710	2.83
Control	254.8	842	3.30
−25%	255.9	931	3.60
Baking powder			
+50%	257.0	918	3.57
Control	254.8	842	3.30
−50%	250.2	608	2.43
PROCEDURE VARIABLES			
Mixing time			
3 minutes	252.0	790	3.13
6 minutes	253.6	850	3.35
9 minutes	246.3	780	3.16
Batter quantity			
250 g.	206.0	710	3.44
300 g.	252.5	852	3.37
350 g.	298.0	937	3.13
Baking temperature			
325° F.	247.7	687	2.77
375° F.	252.5	852	3.37
425° F.	259.0	830	3.20

Series II

A limited comparison was made of the method (formula and procedure) of the A. A. C. C. and that of our laboratory as a basis for judging the baking quality of cake flour.

In this study we observed the effect of formula variables (sugar, fat and liquid) for both methods. Two samples of cake flour were the subjects of the comparison. The analyses of the flours are:

	Flour A	Flour B
	%	%
Moisture	13.1	10.9
Protein (13½% moisture basis)	7.95	8.02
Ash (13½% moisture basis)	0.349	0.33
Viscosity	57.0	40.0
pH	5.0	5.25

General Observations

Less difference was observed in baking quality of the two flours as judged by the grain, volume and crust of the cakes prepared by the A. A. C. C. method than by the laboratory method. In our opinion the A. A. C. C. method should be modified to include whole egg in the recipe in place of egg albumen (either dry or fresh) or supplemented by a recipe calling for whole egg.

It is extremely interesting to note that the two flours did not respond to the variables in a similar manner for the two methods of cake preparation. Flour "B" gave cakes with better volume when the A. A. C. C. method was used, while "A" flour produced the better cakes with the laboratory method. In all cases the cakes made with Flour "A" had more uniform grain and brighter crusts than those from Flour "B."

The sugar tolerance of Flour "A" was greater than of Flour "B" by the laboratory method, whereas Flour "A" showed less sugar tolerance than "B" by the official method.

We observed that the general effect of fat variable was the same for both flours with both methods of cake preparation.

The general effect of liquid variable was the same for both flours with both methods of cake preparation.

The weight, volume, and specific volume of the cakes prepared from both flours by both methods of cake preparation are shown below.

LABORATORY FORMULA AND PROCEDURE

	Flour A			Flour B		
	Weight of cake	Volume	Specific volume	Weight of cake	Volume	Specific volume
	G.	*C.c.*		*G.*	*C.c.*	
Control	249.3	805	3.23	251.6	737	2.93
+ liquid	251.0	657	2.62	253.0	557	2.20
− liquid	257.0	900	3.50	264.0	852	3.25
Control	257.8	825	3.20	251.0	795	3.16
+ sugar	268.5	880	3.40	258.5	757	2.93
− sugar	250.6	720	2.87	252.5	702	2.78
Control	248.1	790	3.18	250.7	787	3.14
+ fat	255.2	790	3.10	249.3	727	2.91
− fat	253.1	837	3.32	248.0	795	3.20

A. A. C. C. Formula and Procedure

	Flour A			Flour B		
	Weight of cake	Volume	Specific volume	Weight of cake	Volume	Specific volume
	G.	*C.c.*		*G.*	*C.c.*	
Control	241.0	630	2.62	246.5	715	2.91
+ liquid	247.4	560	2.27	245.0	570	2.32
− liquid	245.4	682	2.78	259.0	760	2.94
Control	238.0	645	2.70	242.0	717	2.96
+ sugar	245.5	600	2.45	239.0	692	2.89
− sugar	249.0	635	2.55	252.2	662	2.62
Control	238.0	645	2.71	244.7	697	2.85
+ fat	242.8	660	2.72	251.0	725	2.89
− fat	241.0	642	2.67	246.5	720	2.92

Photographs illustrating these studies are shown in the following figures:

Series I

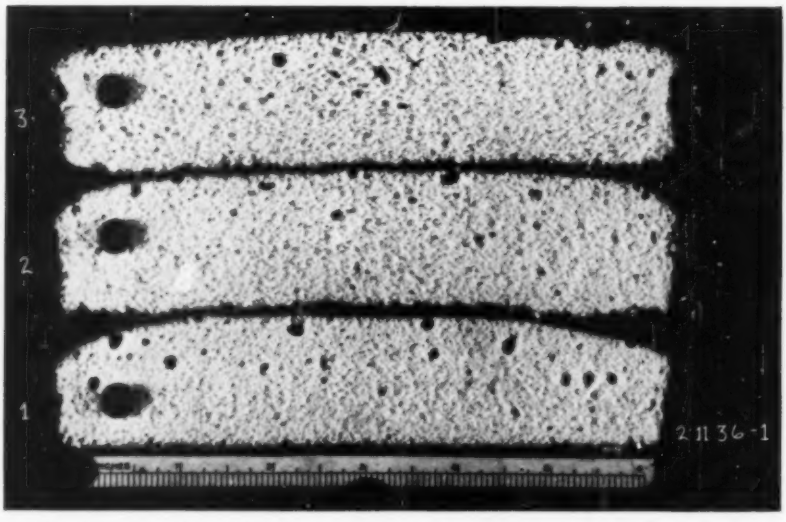

Figure 1. Formula variable—Sugar. 3. +25% sugar. 2. Control. 1. −25% sugar.

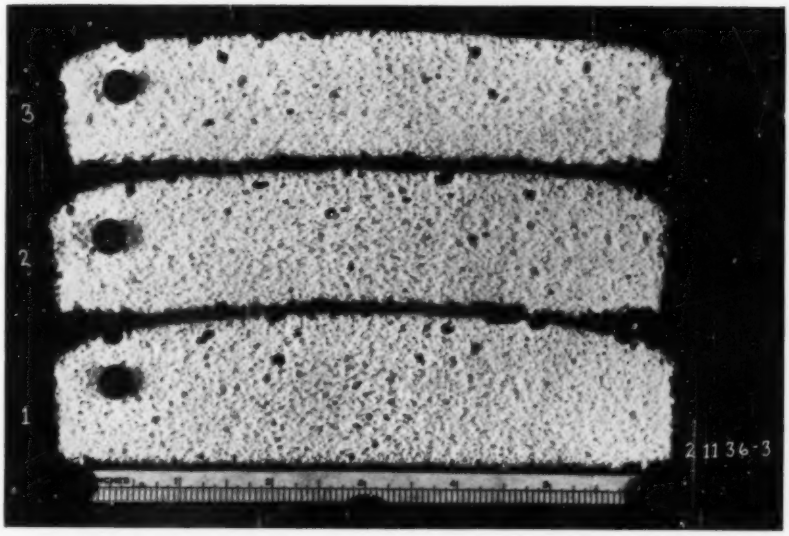

Figure 2. Formula variable—Fat. 3. +25% fat. 2. Control. 1. −25% fat.

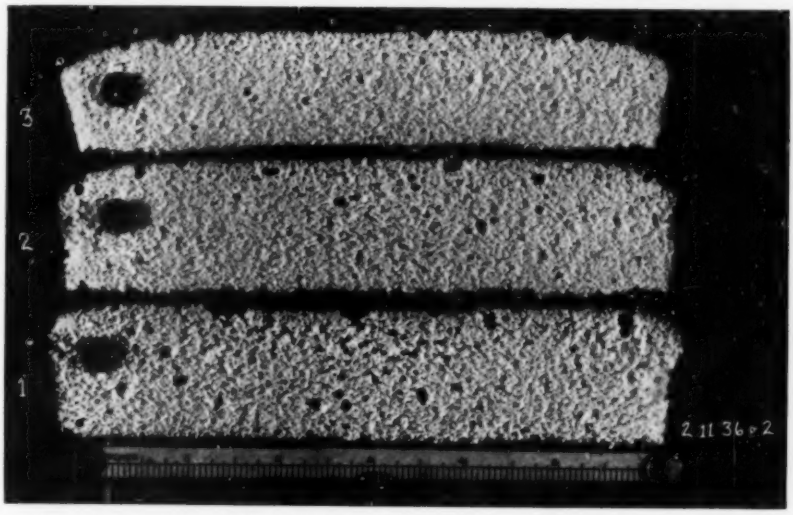

Figure 3. Formula variable—Liquid. 3. +25% liquid. 2. Control. 1. −25% liquid.

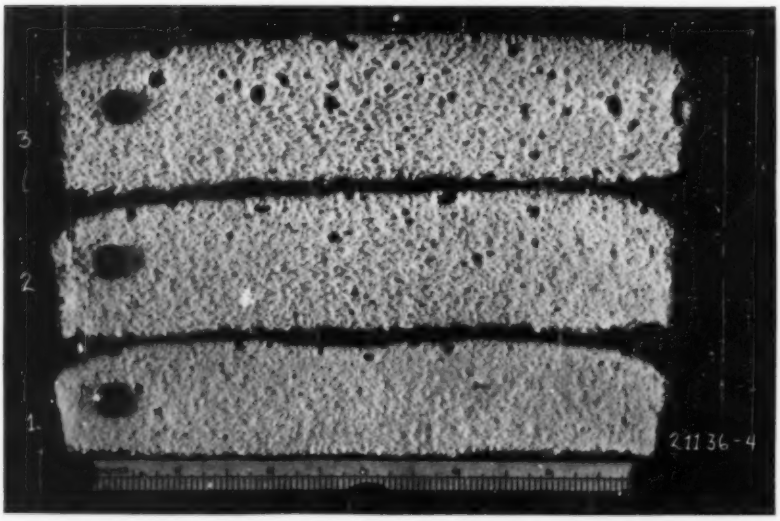

Figure 4. Formula variable—Baking powder. 3. +50% baking powder. 2. Control. 1. −50% baking powder.

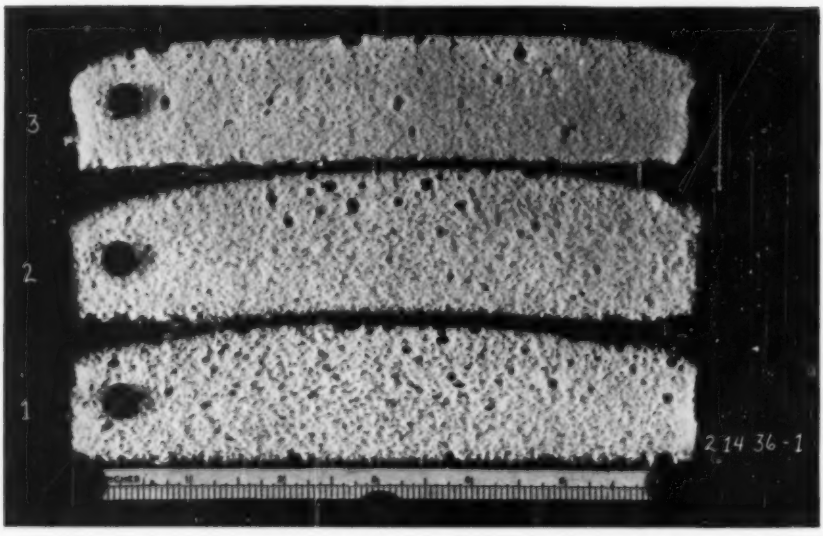

Figure 5. Procedure variable—Mixing time. 3. 9 minutes mixing. 2. 6 minutes mixing. 1. 3 minutes mixing.

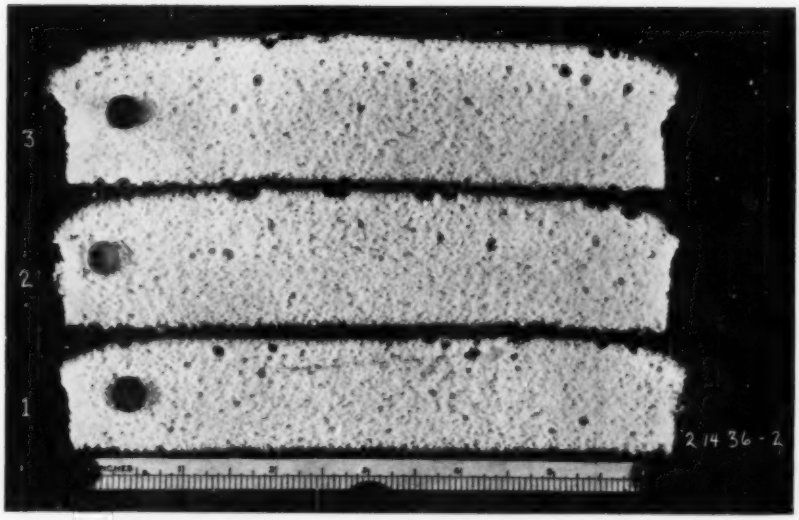

Figure 6. Procedure variable—Quantity of batter. 3. 350 g. 2. 300 g. 1. 250 g.

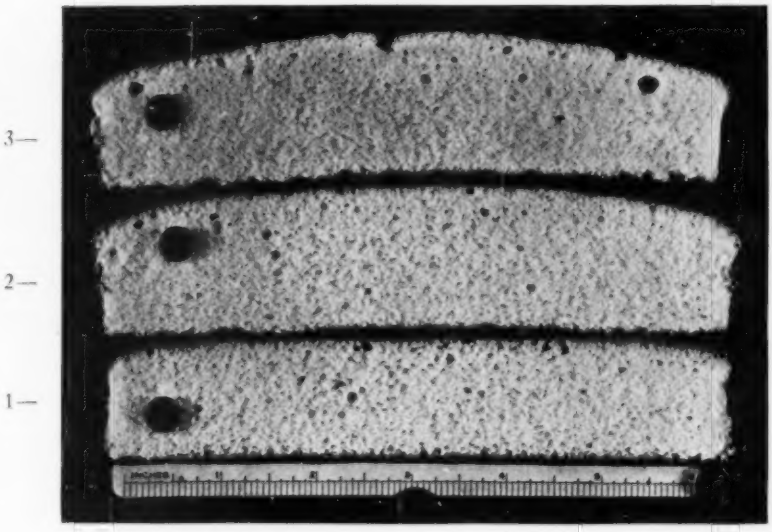

Figure 7. Procedure variable—Temperature. 3. 425° F. 2. 375° F. 1. 325° F.

Series II

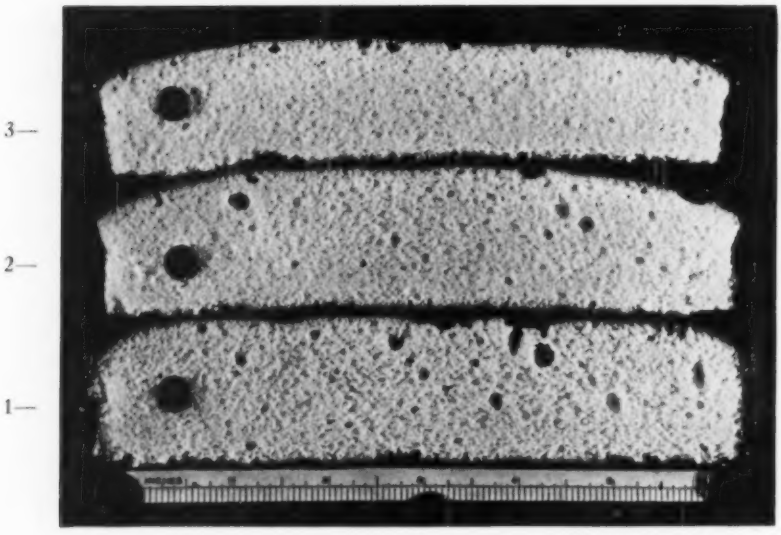

Figure 8. Comparison of laboratory and A. A. C. C. methods—Liquid variable.
3. +25% liquid. 2. Laboratory control, flour A. 1. −25% liquid.

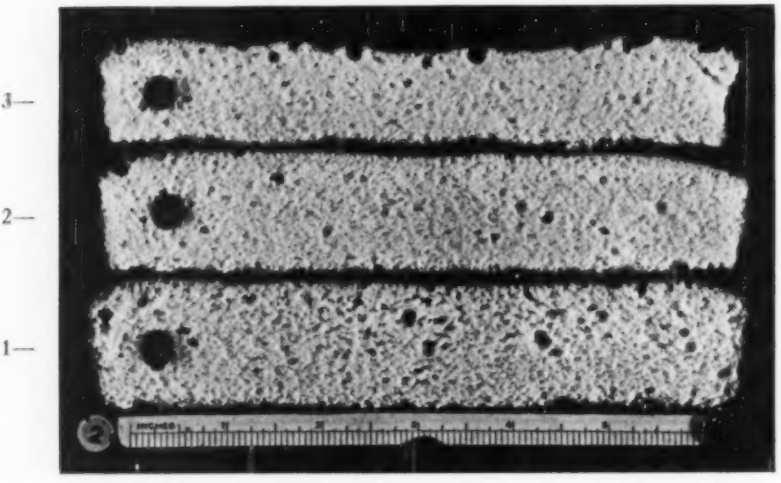

Figure 9. Comparison of laboratory and A. A. C. C. methods—Liquid variable.
3. +25% liquid. 2. Laboratory control, flour B. 1. −25% liquid.

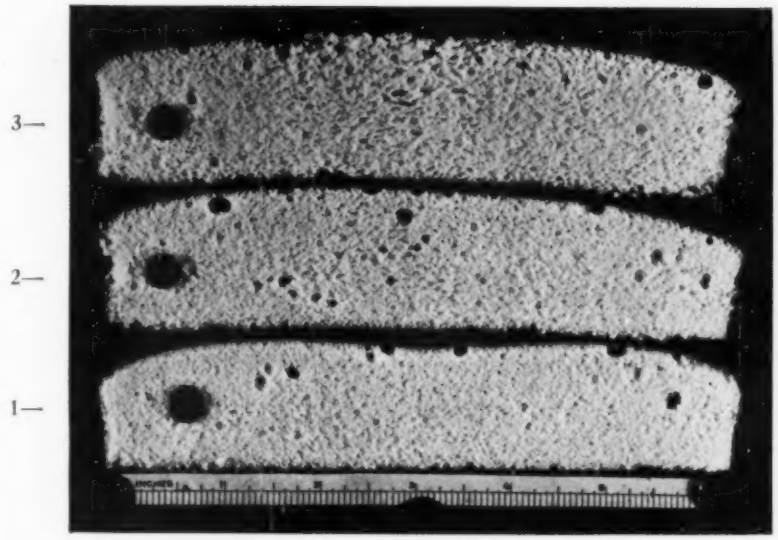

Figure 10. Comparison of laboratory and A. A. C. C. methods—Sugar variable. 3. +25% sugar. 2. Laboratory control, flour A. 1. −25% sugar.

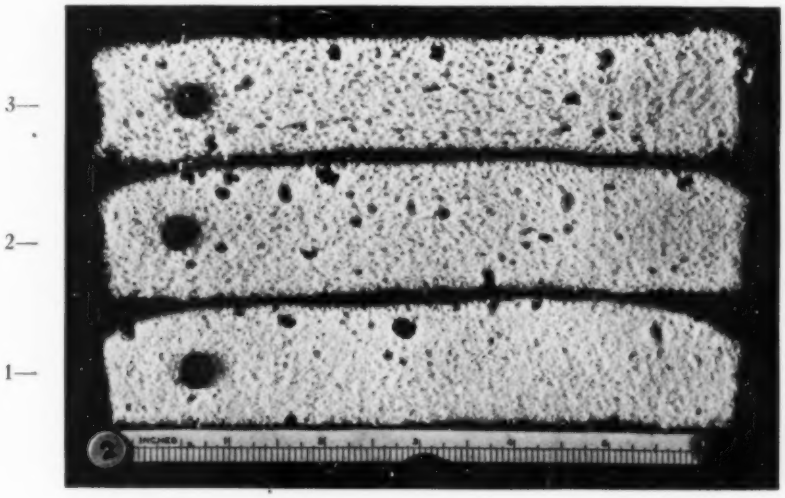

Figure 11. Comparison of laboratory and A. A. C. C. methods—Sugar variable. 3. +25% sugar. 2. Laboratory control, flour B. 1. −25% sugar.

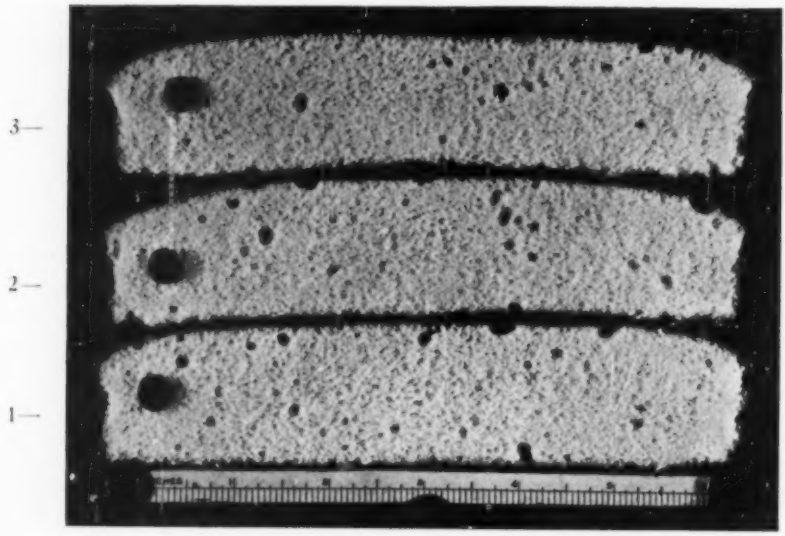

Figure 12. Comparison of laboratory and A. A. C. C. methods—Fat variable. 3. +25% fat. 2. Laboratory control, flour A. 1. −25% fat.

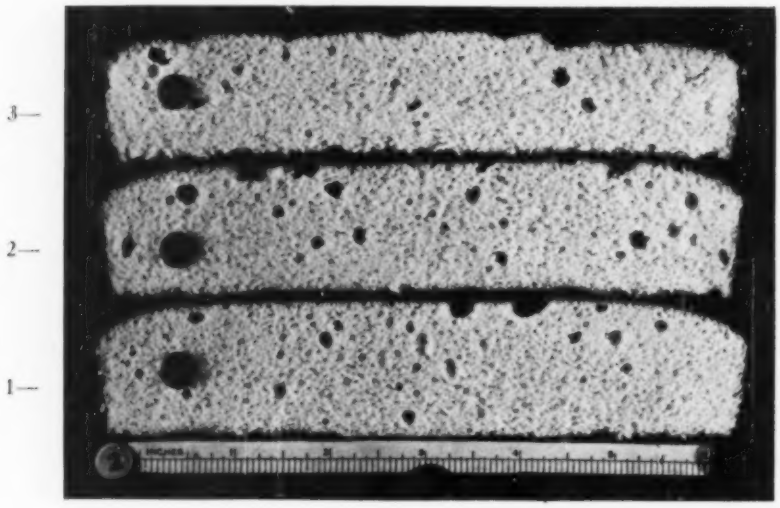

Figure 13. Comparison of laboratory and A. A. C. C. methods—Fat variable. 3. +25% fat. 2. Laboratory control, flour B. 1. −25% fat.

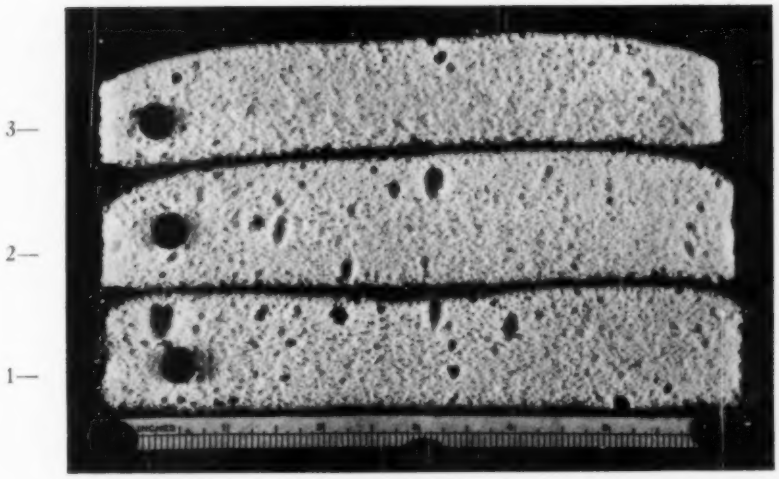

Figure 14. Comparison of laboratory and A. A. C. C. methods—Liquid variable. 3. +25% liquid. 2. A. A. C. C. control, flour A. 1. −25% liquid.

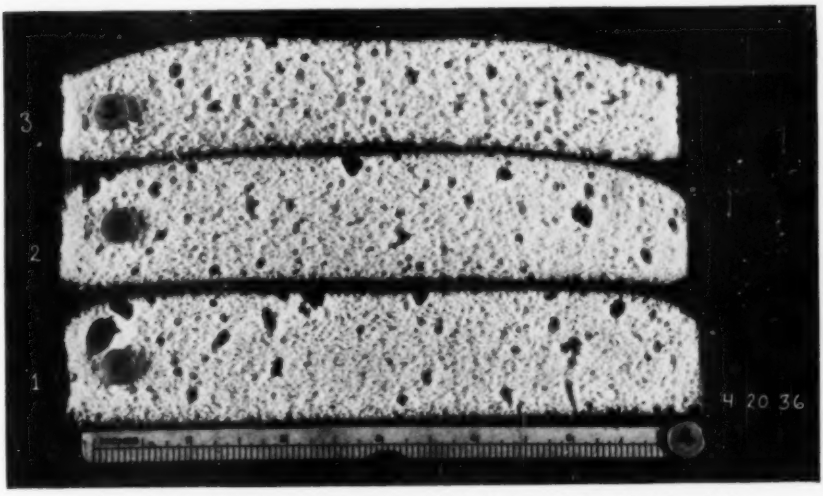

Figure 15. Comparison of laboratory and A. A. C. C. methods—Liquid variable. 3. +25% liquid. 2. A. A. C. C. control, flour B. 1. −25% liquid.

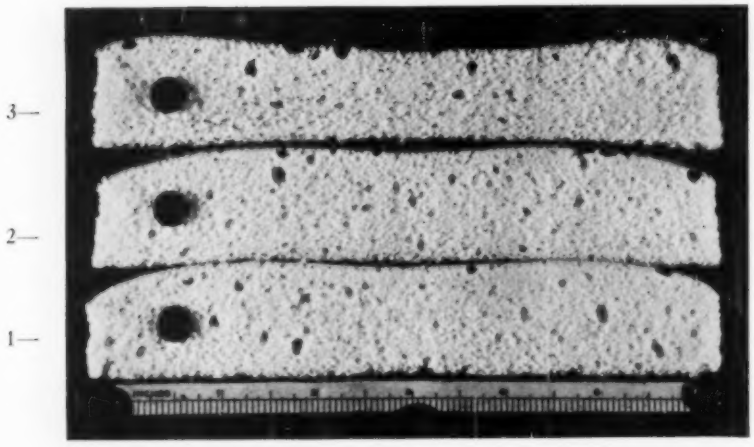

Figure 16. Comparison of laboratory and A. A. C. C. methods—Sugar variable. 3. +25% sugar. 2. A. A. C. C. control, flour A. 1. −25% sugar.

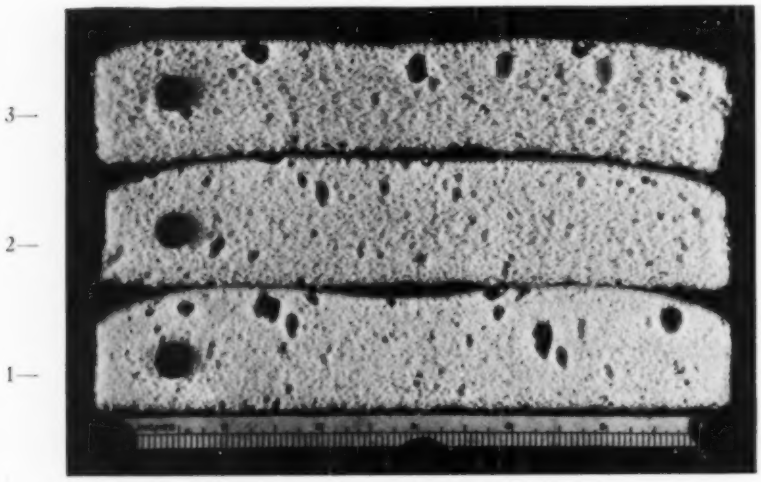

Figure 17. Comparison of laboratory and A. A. C. C. methods—Sugar variable. 3. +25% sugar. 2. A. A. C. C. control, flour B. 1. −25% sugar.

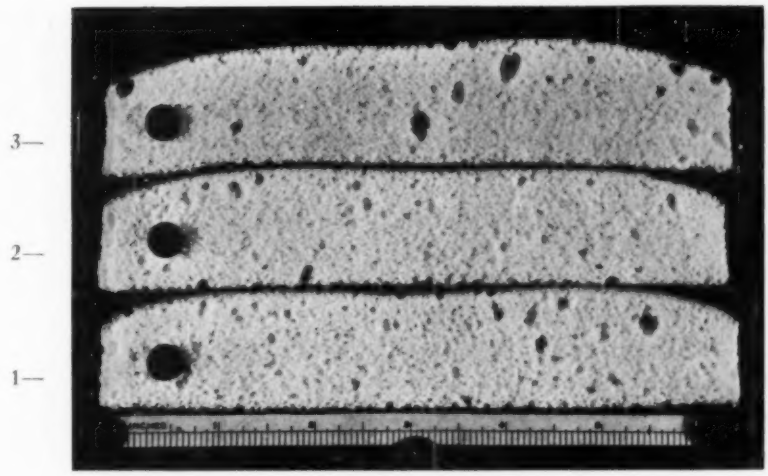

Figure 18. Comparison of laboratory and A. A. C. C. methods—Fat variable.
3. +25% fat. 2. A. A. C. C. control, flour A. 1. −25% fat.

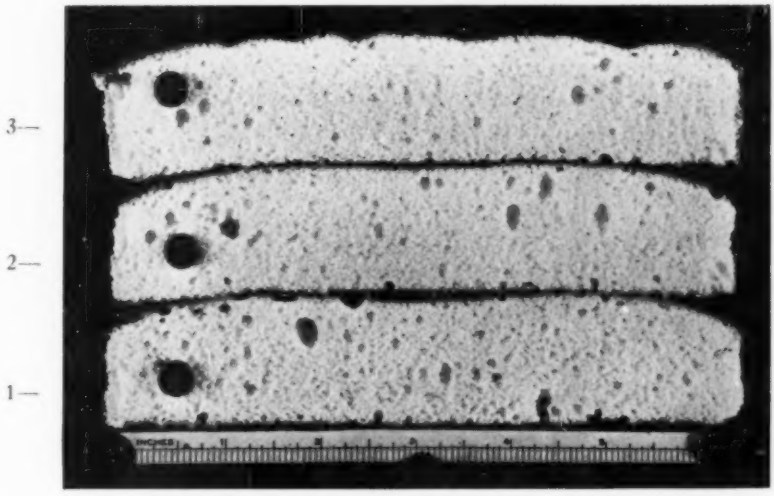

Figure 19. Comparison of laboratory and A. A. C. C. methods—Fat variable.
3. +25% fat. 2. A. A. C. C. control, flour B. 1. −25% fat.

THE SCIENTIFIC BASIS FOR EXPERIMENTAL BAKING TESTS [1]

MAX C. MARKLEY

Division of Agricultural Biochemistry, University of Minnesota, St. Paul, Minnesota

(Read at the Annual Meeting, May 1937)

The problem of finding a common basis satisfactory to all for making baking tests is probably the most serious one facing the American Association of Cereal Chemists today. It is easiest to say that the situation is hopeless, and that it is useless to attempt to reach a common understanding. It is also easy to state dogmatically that we should accept some one existing procedure and base all our work on it. However, there is still a third alternative; this is to find out those items in baking procedures that now are acceptable to all, and build upon them. We have laid down exact performance specifications for baking equipment. It is unwise to specify manufacturers since we have had sad experience in our one attempt to do so, and also by such action we may discourage research on the part of other equipment makers.

Specifications for equipment have been the most fruitful result of all our research on standardization of test baking. We have made some progress in the establishment of specifications for the non-flour ingredients when the baking test is to be used for flour testing, but have given no attention to the establishment of type standard flours for the use of laboratories testing other ingredients, such as yeast, malt preparations, milks, or yeast foods. It may not be at all wise for us as an association to attempt to set up such type flours each season, but it is a project worthy of our attention.

When it comes to selecting a procedure that will be acceptable to all, then there is much difficulty. At the base of all the confusion around the proper type of baking formula and procedure is the extreme diversity of information required from the baking test. The mill chemist desires a test that will above all indicate the relative uniformity of the product of his mill, and secondly generalized information concerning its gassing rate, mixing tolerance, and state of oxidation. The bakery chemist desires to know what changes if any are required in order to fit each successive lot of flour into the production scheme of the commercial plant. The chemist in the wheat-breeding station has to find out how the baking quality of new varieties compares with

[1] Paper No. 1518, Scientific Journal Series, Minnesota Agricultural Experiment Station.

that of the present commercial varieties. The chemist in any one of the allied trades wants to know how to fit his product into commercial processes. This partially indicates the causes of the difficulty which we as an association have had in the standardization of the baking test.

In addition to these differences in purpose of making baking tests, we are dealing with a biological medium, flour, the properties of which are affected by many factors. The climate is of extreme importance as all cereal chemists realize. Possibly, though it has not been realized just how, the changes in climate have caused us to change our baking procedures. If I may be permitted to draw upon observations made during the fifteen years of my experience in cereal chemistry, I may be able to illustrate this point.

In the early twenties in the Southwest the major problem was strength. High-protein wheats were scarce and at a premium. Diastatic activity was rarely a serious problem. My earliest baking method involved the hand mixing of pound doughs until they became dry and smooth, then fermenting according to a rate based upon the maximum rise during the first stage. In effect this method gave longer mixing and fermentation to high-protein flours than to weak ones. Then in the 1924 crop in the Southwest there began to appear scattered lots of low diastatic wheats. It was at this time the Werner method was introduced into the Ismert-Hincke laboratory by Ralph Herman. It was then I made my first acquaintance with the method. Few other laboratories adopted it for several years, since protein content was still the great concern, but with the onset of high-protein crops in 1927 and successive years strength was no longer of prime importance to the mill chemists. This change in climatic conditions which produced the high-protein wheat simultaneously reduced the diastatic activity. Now determination of the gassing rate became the all-important concern of the Southwestern chemists, and since the Werner method was well adapted to this purpose it was adopted in many laboratories.

The "Pup" test, as the Werner test became commonly known, never was widely adopted in the spring wheat milling laboratories. Here diastatic activity was never the all-important concern, but instead in the dry years there was a deficiency of strong spring wheats, and the important problem was one of obtaining the best types of other wheats for blending into the spring wheat mixes. Many of the laboratories found that their old expansion type of test still gave them the desired information, and that the "Pup" test in any of its permitted supplements offered no new advantage. The result has been that few of the spring wheat laboratories in Minnesota have adopted the small-loaf test. Most of the experiment station laboratories have

made much use of the small test, but now the ordinary procedures in several of the stations have little resemblance to the original basic procedure. The experiment stations like the method because it is economical of flour, which is very important in variety testing.

From the foregoing discussion it appears probable that our baking methods are functions of the climatic conditions, and since we cannot predict the climate, it is likewise impossible to predict just what property of the flours will need emphasizing ten years from now. Utterly unexpected factors come into the picture, such as the slimy gluten bug which is causing so much trouble in Europe at present, and necessitate changes which we do not now anticipate in our present procedures. To me it appears essential that our baking methods should be kept fluid at all times; we should never allow them to become crystallized and rigid.

In the course of my own work at the Minnesota Agricultural Experiment Station I have been unable to use exactly the same technic from year to year. Prior to 1929 the method in use had been the basic test as nearly as possible carried out according to the official methods. In 1929 the basic method failed to differentiate the varieties according to baking strength, since hand mixing was inadequate for the proper dough formation. I then used the paddle blade in the Hobart mixer as my first deviation. The next season the experimentally milled flours were extremely low in gassing power, so malt flour was added to the formula, thereby using two deviations simultaneously. After a Hobart-Swanson machine was made available, it was found that the official mixing time as specified for this instrument was insufficient and a third deviation was incorporated. Later additional sugar was substituted for the malt flour. Mixing time differentials were then introduced. This season I have made extensive use of the Latin Square method of simultaneously varying both mixing and fermentation times. By this method I have been able to get information impossible to obtain by the use of but a single supplement at a time to the official method.

This Latin Square method which was first introduced into experimental baking by Clark (1937) [2] is particularly valuable in determining the baking characteristics of unknown flours, and as a research method for the determination of correlations between the variables entering into the production of optimum and satisfactory bread. It is too cumbersome for routine work such as that of the mill laboratory, but by the occasional use of this technic it is possible to better design and interpret the simpler tests of every day use. The method of using

[2] Clark, Rowland J. Baking according to flour characteristics. The Northwestern Miller 190: 15, 24–25 (1937).

this Latin Square method of baking can be illustrated by a series of models I have prepared.

The first model (Figure 1) represents a high-protein hard-spring wheat flour. Along the one axis fermentation time, expressed in hours, is represented; mixing time in minutes is shown on the other horizontal axis. The vertical scale represents the quality of the bread for each combination of mixing time and fermentation time. The quality is expressed in a single figure score in which volume represents

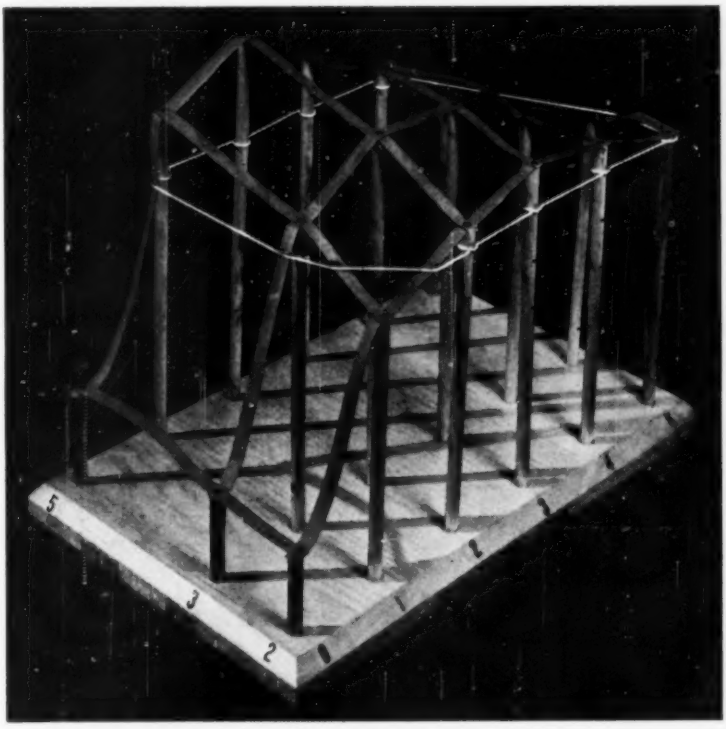

Figure 1. Three-dimensional model showing the effect of simultaneously varying the mixing and fermentation times upon the combined-quality score of the resulting bread made from a strong, high-diastatic spring-wheat flour.

60%, grain 20%, texture of crumb 10%, and external appearance 10%. A score of 60, which is represented on the models by a horizontal white line, is about the minimum for high quality bread.

This high-protein flour has the potentiality of producing good bread over a wide range of conditions. The formula used was that of the basic method with the exception that 6% sugar was substituted for the regular 2½%. There was no appreciable evidence of diastatic deficiency through the five hours of fermentation. When a mixing

time of two minutes was employed the best loaf was at three hours' fermentation; for a three-minute mixing two and a half hours was the optimum; at five minutes' mixing the best loaf of the entire series was obtained at two hours' fermentation. The loaves panned directly from the mixer were very small in volume with a cake-like crumb very white in color. At one and two hours' fermentation there was an increase in loaf quality by lengthening the mixing period from two to five minutes; at three and four hours there was but little effect upon lengthening the mixing time; at five hours' fermentation extending the mixing period reduced the loaf volume.

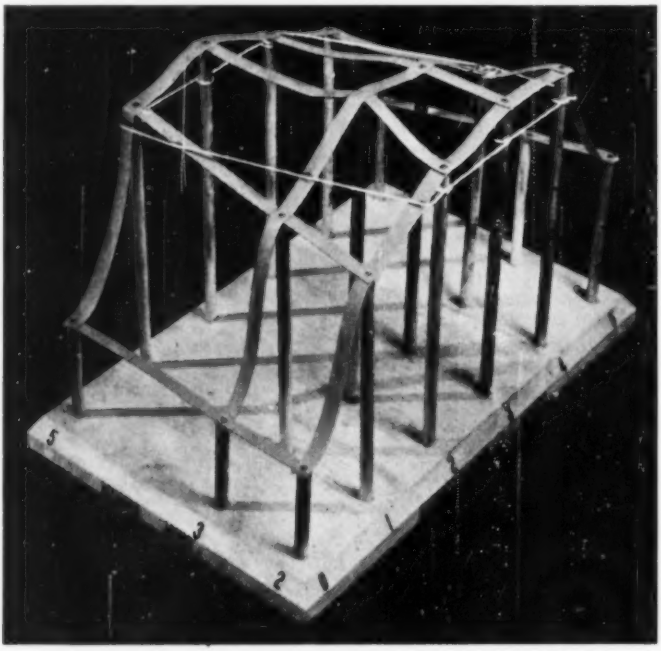

Figure 2. Three-dimensional model showing the effect of simultaneously varying the mixing and fermentation times upon the combined-quality score of the resulting bread made from a weak, low-diastatic spring-wheat flour.

This model well demonstrates the close relation existing between mixing time and fermentation time. There appears to be a negative correlation between mixing and fermentation for the production of the optimum bread, which means that within a limited range one can partially replace the other.

The second model (Figure 2) is of an inferior spring-wheat flour. This flour is definitely low in diastatic activity as indicated by the low scores for the five-hour loaves. The flour, also, does not stand much mechanical abuse as is indicated by the optimum loaf for the

series being at three minutes' mixing and two hours' fermentation instead of five minutes and two hours in the instance of the stronger flour. If these flours had been baked under the normal conditions of two minutes' mixing and three hours' fermentation there would have been no differentiation, no indication of the conditions for producing the optimum loaves from either, and no definition of the range for good bread production for either flour.

The third model (Figure 3) is that of a low-protein hard-winter wheat flour. The point of optimum bread production is three minutes'

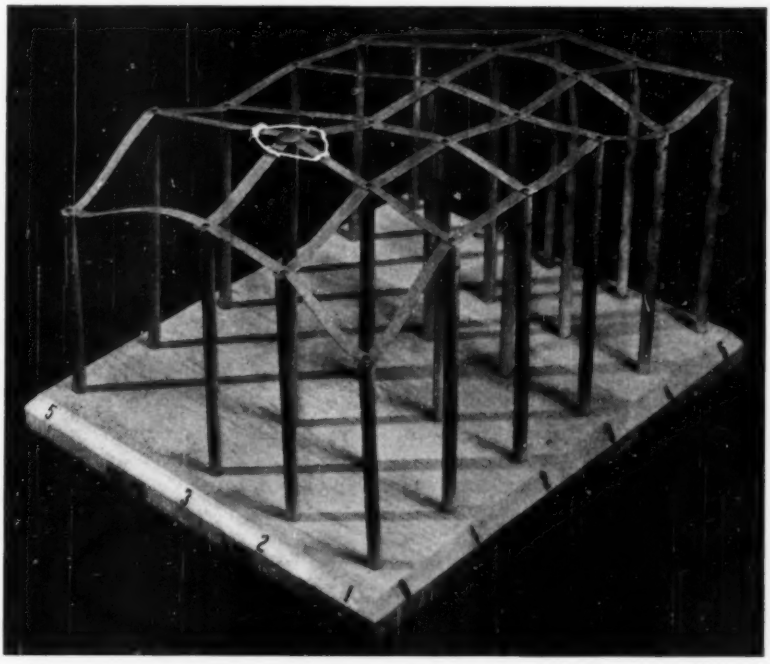

Figure 3. Three-dimensional model showing the effect of simultaneously varying the mixing and fermentation times upon the combined-quality score of the resulting bread made from a low-protein, hard-winter wheat flour of good diastatic activity.

mixing and one hour fermentation, but the range under which acceptable bread can be produced is very limited. Fairly good bread can be produced from this flour over a wide range of conditions. It is of interest to note that the bread which had been panned directly from the mixer was of much better quality than similar bread produced from the strong Canadian flours. There could scarcely be a better demonstration than this of the absolute need for some fermentation for strong flours. If the optimum conditions for this weak flour were to be taken as a standard test, there would be no differentiation between this weak flour and the strong springs.

One-minute mixing was not employed with the spring-wheat flours because it was impossible to secure a smooth dough in so limited a time from these flours.

From a study of such data as are embodied in these models it appears very questionable practice to subject all flours to a single fixed condition of mixing and fermentation in the baking test. The determination of a single point in such a system as is represented in these models, even though replicated until there can be no reasonable doubt as to its accuracy, is of very limited value if no other points on the surface are known. One can only guess the location of that point with respect to the optimum and the limits of good bread production.

It may be heresy for me to say I would rather have a crude representation of the optimum and the range of good bread production of a given sample of flour than the mean results of twenty or more loaves baked under the most highly standardized and rigid single set of conditions, but even though such a statement should mean the abandonment of our standard test, which it need not, I am making it. If I could determine, even roughly within but three categories each, the mixing time, the fermentation time, the response to oxidizing agents, the gassing power, and the absorption, I could tell any baker in language which he could readily translate into his own shop practice, how a given flour should be handled; but if I were to tell him the loaf volume by a given method was 580 c.c., the grain 97, the diastatic activity 235, and the absorption 62%, he would not have any definite information to go on unless he had a great file of such data together with the shop conditions under which he had baked the flours. How much simpler it is to tell the baker a given flour requires a long mixing time, a short fermentation, a light dose of oxidizing improver and a small amount of malt and much water; then he readily can make the necessary adjustments without impairing his quality during the trial period. Of course such crude terms are painful to many scientists to whom extreme accuracy is a passion. Still we don't do test baking for the purpose of covering report sheets with six-decimal-place figures; we bake to determine how a flour or other ingredient should be handled in commercial and home baking. If all bakeries were alike there would be reason for the precise standardization of baking tests, but since bakeries vary and flours vary we should keep our testing methods fluid so as to be able at all times to secure the essential data.

SYMPOSIUM—THE CORRELATION OF LABORATORY BAKING TEST RESULTS WITH SHOP PRACTICE

(Papers Read at the Annual Meeting, May 1937)

HARRY G. BROUILETT

The American Society of Bakery Engineers

In presenting this paper to the American Association of Cereal Chemists, I wish to express the gratitude of the American Society of Bakery Engineers for the privilege accorded our Society of a place on your program. The bakery engineers fully recognize and appreciate the valued services heretofore rendered our Society and the baking industry by your Association and by the individual chemists representing the milling industry. So it is with this thought in mind that we respectfully present this paper.

We come to you we hope with some suggestions representing the thoughts of the average bakery engineer, among whom are many outstanding bakery production men.

When notified by Mr. Johnnie Roberts, President of the American Society of Bakery Engineers, that we had been invited to participate on your program, I was also advised to meet at the earliest possible date with Mr. George Garnatz of your Association to discuss with him the subject to be presented. In order to obtain the views of production men on this subject I immediately wrote to about twenty members of the A. S. B. E. in various sections of the United States. Receiving replies from these men it was pleasing to note the harmony of thought that prevailed in interpreting the need and expectation of the production men from the mill chemist.

After reading the many letters that I received and discussing this subject matter with several others, it was found that the subject naturally falls into two divisions—first, that of closer cooperation between the cereal chemists and the bakery engineers, and second, the specific problems which the engineer would like to have the chemist solve for him.

Closer Cooperation

The cereal chemist must know the problem of the production man in order to help him. In the past the mill chemist has furnished the baking industry with only meager information, principally with the analysis of a given flour, such as the protein, ash and moisture percen-

tages. In making baking tests the cereal chemist has been primarily interested in the response of the flour to gas production tests. The gas production test is important but we believe it should be extended to include gas retention. The rate of gas production and the ability of the flour when mixed into a dough to retain the gas, thereby effecting the desired mellowing of the gluten, would, if determined by the cereal chemist, be greatly appreciated by the man in charge of production.

The chemist must always remember that his job is to help the baker; therefore he must be bakery minded. He must see the bakers' problems as he is confronted with them. It is fully appreciated that the chemist can not be expected to iron out all the bakers' difficulties by tests conducted in his laboratory. The chemist must, however, become more bakery conscious. He must know more of the problems that confront the man in the bakery who receives a lot of flour and who is expected because of his knowledge of baking to produce quality bread having good eatability. The chemist who is bakery minded should, after conducting the laboratory test, be in a position to give a comprehensive report on a specific lot of flour. The baker then would merely have to make the necessary changes that experience in his plant has taught him are required. This would save much time and patience, to say nothing of the good will that would accrue if each lot of flour were accompanied by such a report.

The chemist should correlate his tests with shop conditions so that the results will be readily applicable to the production man's problem, making his tests in so far as possible a miniature replica of the operations in the plant. The laboratories of certain firms supplying various ingredients to the baker endeavor in the testing of their ingredients to duplicate in so far as possible the handling of small doughs commensurate with that of small bakeries. This method has proved its value; it gives the chemist a fair picture of the results that can be expected in most bakeries.

Having accumulated definite information, the cereal chemist should be able to answer all the questions which the production man or the baker asks about the ingredients he uses. In order to improve the quality and value of his work, the chemist should check shop results against his laboratory findings. This may require occasional plant calls but the contact and experience gained from such practice will very greatly compensate him and his company for the cost entailed in this effort.

The chemist's recommendation to the production man might well include certain known variables that he has encountered during his tests. The production man today lacks knowledge of the facts concerning most of the flour delivered to his plant. He is given the chem-

ical analysis, but that information, while desirable, is insignificant when compared to the actual need of the production man who wants to know more about the next lot of flour that he will have to use. The chemist's recommendation to the production man might be, for example: (*a*) The rate of hydration of flour. (*b*) The true absorption of flour. (*c*) Rate of gas production in relation to gas retention. (*d*) Fermentation requirements. This quite naturally is tremendously involved; fermentation is not merely the function of gas production and gas retention, but it is a definite complex function that predetermines the palatability and true quality of bread. Flours have been encountered that react better to higher temperatures during fermentation —as, for instance, 82 to 85 and possibly 86 degrees. This type of flour is most rare. Research over long periods of time has proved that doughs, if properly mixed and fermented correctly at temperatures ranging in sponges from 66 to 75 degrees and in doughs 78 to as low as 74 degrees, will produce bread of better quality, with more flavor, better texture and eatability. (*e*) Mixing requirement coupled with mixing tolerance; the speed at which the dough is mixed should be given more consideration not alone by the chemist but also by the mechanical engineer. We have progressed with our mechanics and in certain spheres it is believed that we have gone beyond the optimum. Our high speed mixers are generally believed to have been stepped up beyond the optimum R.P.M. for proper development of gluten and dough mixing. Within the last month I have personally experimented with slow mixing in at least three large plants in three different parts of this country, experiments based on 300 pounds of flour or more. The applicability of slower speed mixing over a longer period of time seems preferable. If the chemist can evolve during the processing of flour a higher rate of hydration, it might then be possible to continue our higher speed mixing. (*f*) While it may not be possible or desirable to recommend the amount of yeast or enzyme activators needed for specific flours, the minimum amount of these required to effect proper fermentation may well be suggested to the production man. Very often the tendency on the part of bakery operators is to increase the temperature of sponges and correspondingly lower the amount of yeast used.

It should be the duty and the responsibility of the cereal chemist to report to the production man the results of his findings *in terms which the baker will understand*. Many letters received from my correspondents in reference to this paper strongly urge that you give serious consideration to this suggestion.

Specific Problems

What is the effect of machining and fermentation on palatability? Aroma and flavor, the baker is told by cereal chemists, are important, and they are most important to merchandise bread successfully. Do the machining and the fermentation of bread doughs have any effect on the eatability of bread? Can the cereal chemist give the production man any information along this line?

What is the effect of mixing time and speed of mixing on the hydration of flour—is there any relation between the three? It would seem that there is. Can the A. A. C. C. through research undertake to solve this problem?

Is it possible to work out a definite correlation between laboratory mixing time and plant mixing time? This may or may not involve considerable work. The fact remains, however, that it is most desirable information, and it is quite within the realm of possibility today. The mixing procedure as followed in laboratories is counter to all good practice in dough mixing. The chemist uses a very high speed mixing machine and it in no way correlates with plant mixing time. Changes can easily be accomplished whereby mixing machines can be slowed down in speed, and with a slightly changed bowl and prong agitator, the mixing of doughs can be controlled in the laboratory to the point where little variation could be observed in the plant. The production man would welcome this information.

Laboratory loaves are usually made by the straight dough process, while in commercial practice the sponge dough method is more widely used. Can this latter method be used in the laboratory, and if not, can we be assured that the laboratory straight dough gives indications which are applicable to the sponge dough procedure? As a matter of suggestion, may I be permitted to offer the following: The sponge dough method can be used to obtain the required optimum information on any specific lot of flour. First, after having determined all chemical information concerning the flour, mix a sponge using 60% of the total flour, and 50% of the total water, including all the yeast and yeast food. Mix for laboratory practice at 72 to 74° and set in a cabinet controlled at 80° F. with only sufficient humidity to prevent crusting of the sponge. This may vary a little in different laboratories. Determine the sponge fermentation time by allowing a full rise; when the first stage of recession is evident, then the time that has elapsed from the time the sponge is mixed until time that the recession takes place can be considered the time of the sponge. Here the chemist might be cautioned that the rise of the sponge alone is not an indication of sponge time. It should be remembered that there is a relation between the

rate of gas production and the ability of the gluten to retain the gas. Should your test indicate that you would require $2\frac{1}{2}\%$ yeast for optimum sponge fermentation, and it is desired to continue testing of flour by the straight dough method, this could in all probability be accomplished by increasing the yeast one half of one percent, to the total of 3%. The fermentation time of the straight dough could be determined by employing 80% of the sponge time.

For example: A sponge is mixed at 72° F. using $2\frac{1}{2}\%$ yeast, and it requires six hours for a full rise and proper mellowing of the gluten.

You would mix the straight dough using 3% of yeast and all of the dough ingredients as used in the sponge dough. Mix at 72° F. and allow to rise 80% in six hours (the time of the sponge). This would be approximately $4\frac{3}{4}$ hours for the straight dough time. If $4\frac{3}{4}$ hours is the optimum fermentation time for the straight dough, you would then fold the straight dough without punching in $3\frac{3}{4}$ hours and send to the make-up unit in one hour without further handling. I have successfully used this method for obtaining the correlation of straight doughs to sponge doughs both in laboratory practice and plant practice.

Frequently a flour under one set of conditions will produce a very poor bread but when conditions or procedure are modified excellent results are secured. The strictly uniform laboratory procedure as used by the cereal chemist in his tests will not be of much help in this problem. Have the cereal chemists anything better to offer than the regulation bakery test?

Very often the formula used in the bakery contains several more ingredients than the formula used in the laboratory. Would it be possible for the chemists to incorporate these ingredients in their standard test loaves so that results may be more closely correlated to actual conditions? Production men, when discussing this phase of the chemists' practice, say that the chemist should include all of the ingredients that they as bakery superintendents or foremen must use. The production man and the consumer know that the baking industry produces today the best bread ever known to man. They recognize the importance of the nutritional value of white bread, and from a merchandising standpoint the baker desires to maintain this high level of nutrition. Any high protein ingredient quite naturally disturbs the protein balance of flour. Minerals likewise have disturbing qualities. As a matter of fact, all ingredients used in bread formulas either activate or slow down fermentation; therefore, the production engineer feels that a complementary formula might be used by the cereal chemist most advantageously for obtaining results in his tests more closely correlating with plant conditions.

The small pup loaves made in the average laboratory are so different in structure from the standard commercial loaf that it is sometimes difficult to forecast plant performance from the results obtained by these small loaves. The engineer's views on the matter are that at

least one one-pound loaf be made, and that one-pound loaves made in duplicate would be preferable.

The bakery engineer appreciates the spirit exemplified by the cereal chemists. He wishes to express his thanks for the splendid cooperation in the past, and he invites even closer cooperation from the beacon lights (cereal chemists) to the end that both may prosper in knowledge.

R. T. BOHN

The Great Atlantic and Pacific Tea Company, New York, New York

The events leading up to the adoption of the standard baking test as the official method of the A. A. C. C. have been fully stated in the literature of our organization. Much important work has been done on the study of the variables influencing the results until today one can proceed with the test with a reasonably accurate appreciation of the significant qualities of a flour which are shown by the baked loaf. The value of any baking test depends on its application to problems of practical interest. In flour we have a material that varies very widely in its properties because of the many factors with which we all are familiar. Analysis only roughly classifies the flour into different groups suitable for particular purposes. In the large general class of bread flours we find flour of widely different baking strength and properties which make it most important to properly evaluate them from an economic standpoint.

The A. A. C. C. baking test offers, to the cereal chemist who really gives it an unprejudiced and thorough trial, a valuable and convenient method for making comparative studies of the baking strength and quality of the flour. It must be understood that the A. A. C. C. method includes supplementary tests designed to permit a study of the effect of mechanical, physical and chemical development of the dough.

From the practical standpoint, the A. A. C. C. test gives the following information about a flour.

Absorption: For all practical purposes the absorption of a flour can be determined in the laboratory by the A. A. C. C. baking test. The absorption obtained is not, of course, the same absorption as used in the shop for the latter varies depending on the moisture content of the flour and is modified by the use of varying amounts of ingredients such as sugar, salt, shortening, degree of mechanical development, and type of fermentation. But in the laboratory the relative absorption of flours can be satisfactorily obtained. *No other baking test* gives more *accurate* results.

Gassing strength: There are chemical and physical methods available

which give accurate numerical figures for the potential gassing strength of a flour. These are used in control work in flour mills and in research laboratories. They are much more accurate than a baking test could ever be. However, the lean formula used in the standard test enables an evaluation of the comparative gassing strength of flours to be made. In the event the regular three-hour fermentation time does not reveal differences and it is desired to determine if differences do exist, the time can be increased until the lack of gas is evident in reduced loaf volume and pale crust color. Experience indicates that if the crust color is satisfactory at the end of the regular three-hour fermentation period, the flour has sufficient gassing strength to take care of all normal sponge fermentation requirements. If desired this can be correlated with maltose number chemically determined and cubic centimeters of gas evolved by various fermentation methods employed. *No other baking test* gives more valuable information as regards gassing strength of a flour.

Gas retention and state of oxidation: We hear a lot about gas retention these days. It is obvious in order to test a flour for gas retention that there must be sufficient carbon dioxide generated during the latter stages of fermentation to support normal fermentation. If a flour is low in diastatic activity and fails to produce enough gas during proof and early stages of baking to raise the dough properly, the flour will need a certain amount of malt preparation in actual production and will also need to be baked with the A. A. C. C. formula modified with additional sugar or malt preparation to insure enough gas. When such adjustment has been made the external and internal characteristics of the loaf, among which are loaf volume, oven spring, break and shred, and type of grain, are of importance in determining the gas-retention properties and baking characteristics of a flour. This information can be used in evaluating the flour for bake shop use as it is directly correlated with actual results in the baked loaf.

For example, flours which give the same loaf volume by the test method do not necessarily give the same results in the bakery unless properly handled. They both have the same potential volume which is, as has been pointed out in the literature, in direct proportion to the protein content, but one may need to be baked with a strong oxidizing agent in the yeast food and with considerable mixing, whereas another should be handled with little oxidizing agent and minimum of mixing. The gas-retention properties and state of oxidation of flour are clearly indicated by the results obtained by the A. A. C. C. baking test. A flour that gives a loaf with good oven spring and smooth, even break by the test method can be counted on to give similar results in the

bakery either by the straight or sponge dough process, whereas a flour that shows poor oven spring and ragged break and shred with broken-down grain will give unsatisfactory results because of similar character in the commerical bread unless the formula and procedure are so adjusted to take care of the sensitive quality of the gluten. *No other baking test* will give more valuable information about the gas retention properties of a dough.

Mixing tolerance: There are ways to record visually the physical changes that take place in a dough during mixing. The Brabender and Swanson recording devices are available for this purpose. These methods are far superior to any baking test method for determining resistance to mechanical modification which is so important from an economic standpoint in evaluating wheat and flour. However, the A. A. C. C. baking test using the Hobart-Swanson mixer intelligently will give much valuable information in regard to relative gluten strength as it affects tolerance to mixing and mechanical development. The behavior of the dough during mixing can be noted by the operator, thus giving additional data not recorded in loaf volume or other loaf characteristics. By varying the mixing time it is possible to say whether one flour will require or stand more mixing than another. It is not possible to express this directly in amounts of mixing in the commercial shop because too many variables, such as type and speed of mixer, enter in to influence the time required. *No other baking test* gives more valuable information regarding the mechanical strength of a flour.

Loaf volume: In general loaf volume has been over-emphasized because it can be expressed as a numerical figure and has been seized upon by many investigators in an effort to compare the baking strength of flour. The loaf obtained in the standard baking test is the result of so many influences that its volume can not be taken alone as an index of quality. If necessary the A. A. C. C. test can be so modified as to bake bread of maximum volume. As such it is then merely an expansion test and grain and texture characteristics are worthless as are the grain and texture of commercial bread when baked to excessive volume by maximum development and excessive proof.

In addition the A. A. C. C. baking test offers a convenient, reliable way for testing the effect of various bakery materials. It can be modified to allow for increased rate of development of the dough, for the addition of milk or malt, yeast foods, etc. The results obtained are paralleled by actual commercial bake shop procedure.

Summary

An intelligent laboratory report on the analysis of a flour would give the color, ash, moisture and protein content and in addition a report on the baking qualities which might read as follows:

Report on baking qualities: This flour is of normal absorption. It will take 2% more water than flour No. 1. It is, however, low in gassing strength and the formula in which it is used should include at least 1% malt preparation of 40° Lintner or proportionately smaller amounts of stronger malt.

The gas retention of the flour is excellent and yeast food may be used if desired, but high percentages will give a tough, rubbery dough from which it will be difficult to remove gas at the molding machine.

The flour will stand considerable mechanical abuse without any injury. The gluten is very elastic and the flour will give a loaf of excellent volume with smooth shred and even break when properly handled.

It is particularly suitable for hearth goods or for use in sponge if bread of large volume with somewhat open texture is desired, in which case a lower-protein, softer flour should be used *in the dough stage.*

This type of report is much more intelligent than one which might read:

Loaf volume.....2100 C.c.
Color.....Good
Baking qualities.....Good

This flour may or may not give good results depending on the conditions under which it is baked and the flour with which it is compared.

Fortunately the cereal chemists of today are making their reports mean something, and I believe the A. A. C. C. baking test procedure with various supplements gives more valuable information in helping them understand the baking characteristics of a flour than any other baking method now in use. *No other baking procedure* so far suggested gives more information or is as conveniently handled.

PEARL BROWN

Perfection Biscuit Company, Fort Wayne, Indiana

In our laboratory the Experimental Baking Test is not a matter of daily routine but its use serves as a means of comparison between unfamiliar flours and those whose shop performance is known.

The Basic Procedure of the Standard Test is used. An arbitrary scoring system as given below is used as a means of interpreting the results for the shop foreman.

Little attempt is made to specify definite quantitative changes in the shop as a result of the laboratory baking. The test is used only to indicate in which direction to proceed in the shop.

Perhaps an example will serve to explain our practice.

A certain flour which has been quite satisfactory in the bread shop is taken as a standard. In our laboratory there are two standard flours, (1) a spring wheat flour and (2) a hard winter wheat flour. All spring wheat flours are compared with the spring wheat flour standard, and the winter wheat flours with the winter wheat flour standard.

An arbitrary value of 10 is given (for the standard) to each of the items listed in the score sheet, thus giving a total value of 70 for the standard flour. Deviations up or down indicate the relative quality of unfamiliar samples. As an example, the values from one of the score sheets are given below:

	Standard	Sample A	Sample B
Volume	10	7	12
Oven spring	10	8	12
Break and shred	10	8	11
Crust color	10	9D	10
Crumb color	10	9	9
Grain	10	7	9
Texture	10	8	9
Total score	70	56	72
Absorption	61%	61−	61+
Remarks		Sticky when mixed and punched.	Very stiff when mixed.

Sample A was definitely a weaker flour than the standard but one from which good bread could be made.

The recommendation to the foreman was as follows:

The spring wheat sample A is weaker than our standard. It will take less water, and a lighter fermentation. It might be well to watch the mixing time also.

Sample B is slightly stronger than the standard. It will take a little more water and a little stronger fermentation.

In actual practice sample A took 2% less water, a little less yeast, and slightly less mixing than the standard flour. The resulting bread was quite satisfactory.

Experience has indicated that observations made from the beginning of the test and noted on the score sheet are of added value in the correlating of laboratory baking with shop practice. It is not easy to attach a numerical value to each observation.

In these score-sheet data, the values assigned to the various characters for the standard are the same only because it simplifies matters to have them so. Almost any scoring system might be used.

This is a very simple way of using the baking test but one which is quite helpful in evaluating unfamiliar products for use in the shop.

R. J. CLARK

Kansas State College, Manhattan, Kansas

The production man in charge of bread baking is vitally interested in the baking performance of his flour. If given the chemical analysis of his flour, such as protein, ash, fat, acidity, crude fiber and carbohydrate content, he has no baking guides. If he is furnished with information on the flour's baking characteristics, such as sensitiveness to oxidizers, malt requirement, absorption, mixing time and fermentation time, together with the mixing and fermentation tolerances, he has definite signals to observe in his treatment of the flour in question.

There is no correlation between the chemical factors of a flour's analysis and its baking performance in the shop. There is a very distinct positive correlation between the performance of a flour in laboratory test baking and the performance of the same flour in bakeshop baking, provided the same formula and general procedure of baking are used in the laboratory as in the plant. Straight dough methods in the laboratory will not correlate with sponge dough methods in the plant. Lean formulas in the laboratory will not correlate with rich formulas in the plant. Laboratory baking, however, can guide plant baking if the laboratory formula and general procedure imitate as nearly as possible the plant operations.

Very few production men follow an absolutely fixed baking procedure. Their objective is to obtain the best bread from their flour, and fixed methods do not always insure optimum bread production. For this reason at least three variables are allowed, namely, absorption, mixing time, and fermentation time. If bakings are performed in the laboratory (using the plant formula and general procedure) and, by means of specific signals, these three variable requirements of a flour are determined, the information can be used as a direct guide for handling the flour in the plant. The exact mixing time obtained in the laboratory may not be the best mixing time for the plant because of the different equipment, but, if one flour is found to require a longer mixing time in the laboratory, it likewise will require a longer mixing time in the plant. In a like manner if a flour requires a higher absorption in the laboratory, it will require a higher absorption in the plant.

Fermentation periods in the laboratory and the bake shop also parallel each other if similar procedures have been followed in the two places.

The pivotal point by which a production man gauges the mixing time of a dough is by the "clean up" in the mixer. This should also form the pivotal point in determining the mixing time in the laboratory. Frequently the drop of the sponge is the pivotal point used as an indication for the end of the sponge fermentation in a plant. It is no different in the laboratory. The end of the proof time in a plant is told from the feel of the dough. The very same test can be applied in the laboratory. The production man judges the absorption required by a flour from the appearance and feel of the dough. This same method of determining absorption in the laboratory is very largely accepted when numerous bakes can not be made. It is therefore evident that laboratory baking test results can be directly correlated with shop practice and used in plant guidance if the plant procedures are followed in the laboratory as closely as possible.

C. N. Frey

Fleischmann Laboratories, New York, New York

The object of our baking test work was simply to show what procedure is necessary in a baking laboratory to duplicate a loaf made in a manufacturing plant.

We wished to obtain information based on laboratory results as to the kind of bread which will be produced in the shop with a given formula. If we know the modifications that must be made in the laboratory we can predict fairly well the type of commercial bread we should obtain. The problem of correlating laboratory results with those obtained in practice is a very complicated procedure. Correlation may be established between a particular laboratory and bakery after careful experimentation has shown what factors must be modified in order to produce a shop type loaf in the laboratory. It is difficult to generalize on this procedure inasmuch as no two bakeries are identical in their equipment, methods, etc., nor is it possible to find two baking laboratories that have identical experimental conditions and identical baking technique. Our work was carried on for the purpose of determining the factors governing laboratory as well as bakery results, and by taking advantage of the information thus obtained we were able to duplicate the commercial type of bread.

The purposes of test baking are numerous and complex but it is not necessary to enumerate them at this time. We were not trying to control the uniformity of the mill product nor to determine flour

properties, diastatic activity, adsorption, or any number of other factors which might be mentioned. This work was confined to the achievement of a single purpose regardless of the type of bread, the type of flour, or the method of making the bread.

L. W. Haas

The W. E. Long Company, Chicago, Illinois

The main purpose of flour testing is to determine whether a flour is suitable for its intended use and to ascertain whether it possesses peculiar characteristics which should be known to the user so that he may modify his manufacturing operations accordingly.

Our attention here will be confined to bread flours, and we are then interested in determining the baking characteristics or the so-called baking quality of such flours. Chemical and physical measurements may characterize certain properties of flour, but it seems no single determination nor even several of such measurements will furnish complete enough information to permit a full characterization of a flour. A baking test, or series of bakes, apparently can give more valuable information than any and all the available physical tests together. Thus test baking is today still the last resort in the evaluation of a bread flour.

Much effort has been spent to devise a standard procedure for making baking tests so that uniform results can be obtained by different testing laboratories. This goal has not been reached as yet. I wonder whether a fixed procedure can solve the problem. Irrespective of the fact that a set procedure deals with flour as the only variable—a scientifically sound premise—the method furnishes results which are difficult to interpret and to correlate with the commercial performance of the flour. The cereal chemist knows well that commercial success depends upon fermentation, mixing, absorption, and stability of the dough, and that the alert practical baker adapts the treatment of the dough to the flour to attain maximum results. Obviously, more promising would be a testing procedure which is identical with, or at least very similar to, the treatment which the flour would be subjected to in commercial use. These ideal testing conditions are almost impossible to realize by most cereal laboratories. Only the laboratory operated by the ultimate consumer has these desirable facilities at its disposal. Most testing laboratories do not even know where and how a flour is going to be used, but even if they knew, they could never hope to have facilities to meet all these varying bake-shop conditions. As a matter of fact, many laboratories have only very primitive facilities.

It is then a problem for each laboratory to decide which baking method will furnish information that it can best correlate with the average bake shop performance of the flour.

It may be possible for some highly skilled and experienced technicians to diagnose correctly all properties of a flour from a single baking test made under fixed conditions as to absorption, mixing, fermentation and pan proof, but we have found it easier and safer to obtain our information from a baking procedure which is closely patterned after the handling of a dough in modern commercial practice. This method has been in use in our laboratory for nearly 20 years with minor modifications from time to time in certain manipulations. We use mechanical means wherever possible to eliminate the personal factor and to subject the dough to similar machine punishment as in the large bakery.

Our formula is an adaptation of a lean commercial straight dough formula calling for 600 g. of flour, 12 g. of yeast, mineral salts equivalent to 1.5 g. Arkady, 10.5 g. of salt, 24 g. of sugar, 12 g. of shortening, and water as required to produce a dough of medium consistency (about 350 Brabender units) such as is used in bakeries with high speed mixing equipment. We aim to produce bread of large loaf volume but, at the same time, with a close and even grain, smooth texture, good oven spring and shredded break.

Our doughs are mixed in a Fleischmann mixer which affords intensive mixing action and produces a dough which is very similar to the commercial dough prepared in a high speed mixer. The mixing time is about 4 minutes. It is varied, if necessary, to suit the flour under test. The dough comes out of the mixer at 81° F. and is fermented at 81° F., as is customary in the well controlled bakery.

The amount of flour mentioned makes sufficient dough in one mix for two loaves. Immediately after mixing, two portions of dough of 475 g. each are weighed and the rest of the dough discarded. Each of these portions is fermented separately. One is given what we judge to be the normal fermentation requirement (which is at present $2\frac{1}{2}$ hours for Southwestern and 3 hours for Northern flour); the other is allowed to ferment 30 minutes longer. The two loaves of bread obtained give valuable indication of the fermentation requirements and the tolerance or stability of the dough.

The dough is punched according to a schedule which gives us the best bread. This schedule is somewhat modified every season to adapt it to the crop characteristics. At present, the total fermentation is adapted as much as possible to the type and requirements of the flour in the same manner as is done in commercial bread production.

The loaves are molded in a full size commercial molding machine and baked in a commerical type pan 9 inches long, 4.5 inches wide, 2.75 inches deep, and having a flare of 0.25 inches. The molded loaves are proofed in a Bailey cabinet at 95° F., similar to the manner used in the bakery. Pan proof is judged by appearance, height of the loaf, and resistance of the dough to a gentle touch with the finger. Generally the proofing time is about 55 to 65 minutes.

The bread is baked in an electrically heated and automatically controlled oven for 30 minutes. The top temperature is maintained at 420° F. and the bottom heat at 460° F.

This brief description of our procedure illustrates that we endeavor to give a flour the same favorable treatment which it may be expected to receive in the commercial bakery. In other words, we try to determine whether a flour can produce good bread if it is properly treated and not merely to find out whether or not it fits into a rigid and unalterable procedure. This way of making baking tests not only gives the flour a fair break, but it also shows up its weaknesses.

An accurate record is made of the treatment given a flour from the mixing of the dough to the baking of the bread. Any peculiarities in the behavior of the dough are carefully noted and repeat bakes are made if the first results are not satisfactory in every respect. In these check bakes, such adjustments as are indicated by the characteristics of the dough and the bread in the first bake, or additions of diastatic or oxidizing supplements, are made if they appear to be desirable. Thus we learn whether a flour possesses normal characteristics or whether it requires special mixing, fermentation or other precautions, or whether the dough from it shows a tendency to tear readily or become sticky or bucky. Such tendencies are indicated in our reports to urge special care in certain respects in the use of the flour in order to avoid difficulties.

The items of significance to us in our baking test are loaf volume, grain and texture, absorption, oven spring and break, crust color, mixing and fermentation tolerance, and the way the dough handles during fermentation and in molding. Abnormalities in mixing, fermentation, and absorption and other peculiarities are often checked by means of the Farinograph.

Loaf volume, grain and texture, and absorption are expressed numerically, the latter in actual percentage used in the dough and computed to a 15% moisture basis; the other items are merely scored. We prefer to score loaf volume rather than to report actual volume figures and we always consider loaf volume in conjunction with grain, texture and break.

A satisfactory bread flour should produce bread having at least a

loaf volume of 930 c.c. per 100 g. of flour (corresponding to 2,780 c.c. or 170 cubic inches per pound of bread), and the bread should also have a close and even grain, a large oven spring, and a well shredded break. Such flour gets a rating of 100 in loaf volume for the reason that according to our experience it produces fine commerical bread in every respect. If the dough from this flour requires at least 4 minutes' mixing time and tends to become neither sticky nor bucky on fermentation, we are satisfied the flour will satisfy the commercial baker. If, in addition, the loaves produced by the normal and the long fermentation treatments are about equally satisfactory, the flour possesses good fermentation tolerance or stability. Flour of these characteristics behaves well in the bakery, and its fermentation tolerance is scored as 105 or 110 or higher.

A flour intended for hearth bread is baked into pan and hearth bread, if the sample is large enough, to determine whether the dough can stand a long fermentation period, stands up well in the proof box, and produces a bold, well-rounded Vienna type loaf.

I have given you in brief our preferred way of making routine baking tests to determine the baking characteristics of a flour. The production of fine bread of commercial type by this laboratory procedure indicates to us the possible commercial performance of the flour under test. At least, our experience has taught us that there is as good a correlation between the two results as can be expected. However, this correlation does not go so far as to indicate accurately the actual mixing, fermentation, intermediate and pan proofing time to be given a dough in the commercial bakery. Responsibility for these factors is properly left to the baker.

C. G. HARREL

Pillsbury Flour Mills Company, Minneapolis, Minnesota

In compliance with your request I am pleased to present the following remarks on the subject "The Correlation of Laboratory Baking Test Results with Shop Practice." I personally believe this subject could be more clearly stated as "The Correlation of Laboratory Baking Test Results with the Results Obtained from Modern Bake-Shop Procedure Under Given Conditions."

Shop practice varies widely and under the general term "shop practice" might come an infinite number of variables, depending upon the number and various shops taken into consideration. I personally believe that many times the reason why we seemingly have many contradictory results between the laboratory bake and plant bake is

because "shop practice" means almost any condition that can be imagined. It is only natural for the plant superintendent who is operating in his sphere to assume that the conditions which prevail in his plant are the ones that are right, and quickly to jump at the conclusion that because another result was obtained in a scientifically controlled laboratory, such a result is not practical from his particular standpoint.

The American Society of Bakery Engineers is to be commended upon the advances it has made in bringing shop superintendents to realize the value of controlled shop conditions. Some cereal chemists have often been misled in attempting a prediction from their baking results, as to what would happen in the bake shop, by frequently overlooking many of the shop variables. In attempting to correlate the laboratory baking test results with the results obtained from modern shop practice, I believe that in many cases entirely too much is expected. The definite fixed procedure which has been more or less adopted as our standard baking test certainly is a step in the right direction. To those people who have contributed so largely to its development we owe a great deal of thanks. It marks a progressive step.

With the results obtained from this fixed procedure, we should be able to meet upon a common ground and discuss general conditions. These results are a general indication of what may occur in shop practice. If one attempts to apply the results from such a fixed baking test to commercial plant conditions on the various types of bread made in this country and in foreign countries, it will only be a question of time before he will be erroneously misled.

I must confess that many years ago my interpretative powers were far better than they are today. At that time I could fairly accurately predict what would happen from a definite fixed procedure, but after years of experience I have seen flours that will react favorably and give excellent products under one set of baking conditions, and under another set of conditions will produce inferior products. Time after time I have observed these results. These results may not wholly be attributed to the flour, because we well know that there are other ingredients which may or may not be present in the dough batch which many times greatly affect the final results. I believe if anyone attempts more than a general indication of what may be expected from a fixed procedure under various shop conditions, he will sooner or later make rather a serious mistake. It is for these same reasons that we believe it is far better for the fixed procedure to be used as a general indication of what may be expected, to be followed by a specific baking procedure which approaches as closely as possible

the particular shop condition in question at the time. We further believe that this is a good scientific procedure. If a man is scientifically inclined, we believe it is far better for him to perform the experiment and obtain the results than to arrive at the results through interpretative methods from another set of data derived from baking conditions of an entirely different character.

We, as chemists, should be first to realize the necessity of our performing these baking tests under the exact conditions under which they will be performed in the industry. If we fail in this realization and attempt to arrive at what may happen in the individual shops through interpretative methods, it is only going to be a question of years before we will find ourselves in a position where shop superintendents will no longer have much respect for our results and interpretative methods. Shop production men are fast making progress in their industry and it may be only a question of time when they will assume the leading role in making all their own tests under the exact shop conditions and leave nothing for interpretation. This practice is now followed a great deal in many of the baking plants in the country. Many of the plant superintendents are well versed—so well versed, that it is difficult for one to hold their respect when he talks in terms of formulas that are totally foreign to modern bake-shop practice. Unless we as chemists can so design some of our baking tests to answer specifically their problems, it is only a question of time before the modern plant superintendent will assume that role and design his own tests for this purpose.

I do not wish to be misunderstood in these remarks. The fixed baking test has a definite function; it is invaluable in its place, but I do not believe that it is meant for the solution of specific shop problems of various types of fermented products.

R. W. Mitchell

Purity Bakeries Corporation, Chicago, Illinois

The subject we are considering today is vital in the successful functioning of a bakery laboratory. The problems involved in correlating laboratory findings with shop practice are of the same nature as those met by the agronomist and mill chemist, with the added responsibility of interpreting the results of the laboratory in a manner to make them fit the restricted conditions of an established shop procedure and a rather rigid schedule.

For the purpose of this brief discussion I will not dwell upon the problems of flour selection such as we must meet at the beginning of

each new crop year, but will confine my remarks to our system of maintaining an effective operating control.

Our routine baking of mill samples of bread flour is done on a formula closely approximating our commercial formula using the sponge method and employing a single arm high speed mixer.

The time required to mix a dough in the laboratory mixer when multiplied by 2.7 will indicate very closely the time that a shop mixer will require when operating at 72 R.P.M.

Our absorption is maintained at a point that is directly comparable with shop practice and may be interpreted without resort to factors or to a deviation figure.

The laboratory formula and practice vary from those of the shop only in the matter of temperature and yeast quantity. These factors are adjusted to make the correlation with shop results approximately exact. We use $\frac{1}{2}\%$ more yeast than the plant uses and bring our doughs from the mixer 5 degrees warmer than the commercial doughs. Mixing characteristics are closely watched and dough qualities carefully noted.

The dough is scaled at $18\frac{1}{2}$ ounces in the standard commercial pan, molded on a standard commercial molder, proofed to condition and checked for dough volume at the time of placing in the oven. The oven is maintained at 450° F. with moisture provided by ample water pans.

The bread is good quality commercial bread and is scored by commercial standards for volume, grain, texture quality, flavor, and crumb and crust color.

Any samples which show a deviation from acceptable grading are subjected to a baking test under the A. A. C. C. "pup" method and suitable supplementary bakings made to determine bromate and malt response and frequently, where indicated, milk response.

The procedure for the "pup" baking involves the use of the standard formula with the following modifications—and let me say that our practice is not recommended in this meeting but it does have some advantages while its faults seem to us no more vital than parts of the recommended procedure:

380 g. of flour are used.
The whole piece is molded on a commercial molder.
The pieces are cut from the large molded unit and scaled at 145 g.
No other deviations are practiced.

I would emphasize my awareness of the criticism that may be leveled at the custom of scaling and let me say that we stand ready to change our procedure if a common practice should be agreed upon.

It was my belief that scaling should be based on dry flour weight together with appropriate adjustment for absorption.

The desirability of mechanical molding is very clear to us. We would gladly use a small molder for the small pieces if the Association agrees on a definite type of equipment.

The loaves are baked in a standard low-form pan and scored in the usual routine. We value the bromate, malt and milk differentials and rely on the interpretations to be made from the loaf characteristics in drawing conclusions as to the character of the flour.

It may be pointed out that samples submitted to the Purchasing Department are examined by the procedure just outlined as well as samples that may be brought in question by the commercial baking test. By pursuing the routine here indicated, the following flour characteristics are quite definitely established: absorption, mixing time, fermentation time, dough quality, proofing characteristics, oven characteristics, volume, crust color, crumb color, grain character, and texture quality.

Incidentally, it is to be borne in mind that all types of flour must be examined, including Canadian, domestic spring, Kansas, Texas and Western, as well as patents and clears from each type.

In the commercial type test, mixing and fermentation time are adjusted to the requirements of the flour, and when the bake is finished the bread must not show evidence of manipulation error. If it does, the bake is repeated. Estimations of presumably corrective modifications have no place in the final decision that is to be made.

Variation in required fermentation time for flours is adjusted by controlling the sponge time and if necessary the dough time.

The laboratory finds it desirable to establish quite definite ranges of protein within which the flour supply must be kept if shop schedules are to be maintained. Ash limits for each grade must be defined as a means of interpreting requirements for the buyer and seller of the flour supply. Moisture determinations are made to permit a check on weights and to determine absorption. Samples must all be slick inspected to insure a knowledge that error has not crept in at the mill.

The sum of all of the tests made on the flour permits the drawing of conclusions that will serve as a guide to the Purchasing Department and make possible pertinent observations which will be of value to the Production Department.

The nature of the test eliminates speculation as to the effects of ingredients and quantities used in the shop; all ingredients and procedure influences, common to the shop conditions, are introduced into the laboratory test.

If you ask the question, "Can your commercial loaf of pan bread

be duplicated in the laboratory?"—my response is "Yes." There may be some exceptions where the conditions are extreme but in general it is very definitely certain that the answer is "Yes." Such being the case, there is no doubt that the laboratory baking can be closely correlated to the shop problem.

G. MOEN

General Mills, Inc., Minneapolis, Minnesota

I have before me loaves of bread made from five different samples of flour which varied significantly in baking characteristics. (See Figure 1.) Each of the five samples was baked by four different

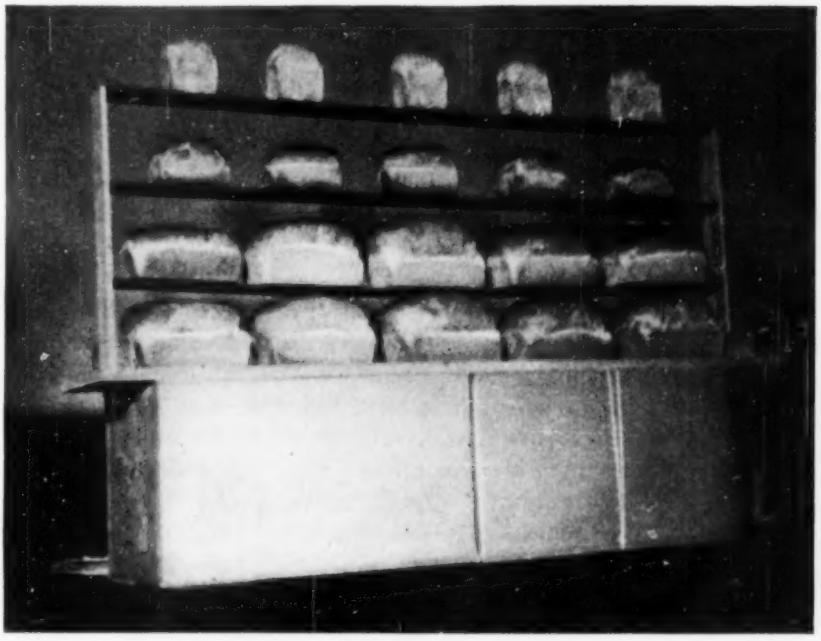

Figure 1.

baking methods. The top horizontal row of loaves on this rack shows results obtained by a pup loaf procedure which was a modification of the A. A. C. C. baking method. The modifications consisted principally in using 82° F. temperature instead of 86°; the addition of 2% shortening and running the doughs through a dough sheeter previous to molding. The second horizontal row of loaves shows results obtained by using an average commercial straight dough formula con-

taining dry skim milk, yeast food, etc., from which pup loaves were baked in pans having a shape similar to that of commercial bread pans. These loaves, which I shall call commercial pup loaves, are shown merely as a matter of interest as, in my opinion, such a test may in time prove useful. The one-pound loaves in the third horizontal row were made by a popular commercial straight dough method and the one-pound loaves in the fourth row were made by a popular commercial sponge dough method. The purpose of this demonstration is to show what in my opinion can be learned about the commercial performance of a flour from laboratory pup loaf bake tests.

The first flour characteristic which comes to our attention in making any baking test is absorption. This, I believe, can be determined as accurately by the pup loaf test as by any other method of baking. The percent of absorption as determined by this method may not be the same as that found to be necessary in large bake shop doughs but the difference in absorption between different flours will be the same in both instances. This is all we can hope to learn under any method of baking inasmuch as the formula and procedure used have considerable effect upon absorption.

The second flour characteristic observed in making bake tests is dough performance. The method used in making the pup loaves in the top row will indicate to any experienced test baker whether or not the doughs will go through commercial machine make-up without difficulty under normal conditions. There was a substantial difference in the dough-handling quality of these five samples of flour and practically the same characteristics were observed in the commercial one-pound loaf, laboratory tests, as were observed in the pup loaf test. Objectional dough characteristics, such as shortness and stickiness, were not as apparent in the commercial doughs, particularly in the sponge type, as they were in the small pup doughs. A dough sheeter was used in handling these pup doughs. This machine has proved quite efficient in detecting desirable and undesirable dough qualities from the standpoint of machine make-up.

As has been explained, each of the horizontal rows of loaves of bread was made by a different method, and from observation of the vertical rows one is able to make a comparison between the results which each flour produced under the four baking methods used. The two outside vertical rows represent flours of poor quality which can readily be seen in the character of the loaves from the two pup loaf methods and the commercial straight dough one-pound loaf method. The commercial sponge dough—one-pound loaves shown in the bottom row—also indicates inferior quality in these samples, but one will note that these loaves are substantially better than the straight dough one-pound loaves from the same flours.

Vertical rows of bread, two and four, show that these flours are considerably better in quality than the samples represented by the two outside rows, and again the straight dough one-pound commercial loaves check quite favorably with the regular pup loaf results shown in the top row. Also again the one-pound commercial sponge loaves are better than the straight dough results obtained by both the one-pound and pup loaf methods.

Referring now to the center vertical row which represents a flour of good quality, note that the regular pup loaf shown at the top and also the loaves obtained by the other three methods show the largest volume and the best external appearance of the five samples tested. The internal characteristics of the loaves from this flour were also superior to those produced by the other samples.

It is quite apparent from the results of the flours used in this demonstration that the commercial sponge dough method used in making the one-pound loaves, shown in the bottom horizontal row, wipes out, to a considerable extent, some of the deficiencies shown in loaves made by the pup loaf and the commercial straight dough one-pound loaf method. From the flour millers' standpoint, this condition is desirable as it enables the miller to correct deficiencies which may occur in his flour before they become sufficiently large to cause the baker any difficulty in the production of bread by the sponge dough method which is the most popular method of making bread today.

It is rather difficult and perhaps impossible to demonstrate conclusively that any one laboratory bake test method is more efficient than all others. The best method of testing any flour is undoubtedly to bake it by the method and under the conditions under which it will be used. The commercial baker does this in running his first dough from a new lot of flour. It is, of course, impossible for the flour mill chemist or the bakery chemist to do this with the large number of samples which it is necessary for him to inspect. He must resort to small units, usually single loaf tests, and choose between a pup loaf method or a commercial one-pound loaf method in which either straight or sponge doughs are used. To be efficient in recognizing flour values it appears to be quite necessary to be familiar with flour performance under all three of these methods and in addition have frequent contact with commercial bake-shop practice. For routine testing of a large number of samples, it is my opinion that either a pup loaf or a one-pound straight dough method is the most convenient and most satisfactory from the standpoint of detecting flour deficiencies. The pup loaf procedure has the advantage of more readily being used in replicate testing, which is quite necessary if reliable information is to be obtained by any method.

Referring again to the loaves shown in Figure 1, it is quite evident that the pup loaves in the top row and the commercial one-pound loaves in the third row from the top present approximately the same picture in regard to the general quality of these flours. The sponge dough one-pound loaves in the bottom row also reflect the same general differences between these flours, but the poor samples represented by the loaves on each end of the rack are much better than the results obtained from these same flours by the straight dough method.

The pup loaf procedure used in making the top row of pup loaves baked in the A. A. C. C. pans is not everything to be desired in a baking procedure, but years of experience with this type of testing have indicated that characteristics as reflected by this method, as a rule, carry through into large-scale production. To be more specific, I mean that such undesirable characteristics as short mixing tolerance, sticky doughs, low volume, ragged shred, dull crumb color, etc., recognized in this pup loaf test, will also be recognized in commercial practice provided the deficiencies are of significant magnitude. Many slight deficiencies recognized in this test are quite often wiped out or covered up in commercial practice which, from a laboratory testing standpoint, is, of course, desirable. This enables the chemist to take steps in correcting deficiencies before they become sufficiently large to cause the baker in commercial shops any trouble.

FURTHER STUDIES ON THE GROWTH OF BREAD MOLDS AS INFLUENCED BY ACIDITY

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(Read at the Annual Meeting, June 1936)

In a previous communication (Kirby, Frey, and Atkin, 1935) [1] the authors reviewed the literature and reported a study of the influence of acidity upon the growth of a strain of *Aspergillus niger*. The results which were obtained with that particular mold furnished evidence in favor of certain conclusions of importance to practical cereal chemistry in general and to the baking industry in particular. With the strain of *Aspergillus niger* studied, it was shown that:

1. This mold has no well-defined growth optimum with respect to the initial hydrogen-ion concentration of the medium, but grows equally well between the pH values of 3.5 to 6.0, provided no acids of specific toxic effect are present.
2. Acetic acid has a marked specific toxicity for this mold.
3. The disinfecting property of acetic acid is a function of pH.
4. The disinfecting action and the retarding action of acetic acid on the growth of *Aspergillus niger* increase with increase in the initial hydrogen-ion concentration of the medium. It is the undissociated acetic acid molecule and not the acetate ion which is the active agent in retarding or preventing the growth of this mold.

Thus, these findings indicated that the bakers' practice of using acidifying agents to control the development of rope in bread would not encourage the growth of mold on such bread.

In order to determine whether or not the above conclusions could be generalized, our studies have been extended to a number of other molds belonging to a group commonly termed bread molds.

Experimental Procedure

PART I

Effect of Initial Hydrogen-ion Concentration upon the Growth of *Rhizopus Nigricans*

In these later investigations the technique and experimental procedure were the same as used in the previous work with *Aspergillus*

[1] Kirby, G. W., Frey, C. N., and Atkin, Lawrence. The Growth of bread molds as influenced by acidity. Cereal Chem. 12: 244–255 (1935).

niger and will not be described in detail here. For all of the studies reported herein, there was used a clear liquid medium—a filtered aqueous extract of bread, as described in our previous communication. With respect to the influence of hydrogen-ion concentration, it was necessary, as before, to confine our studies to the effect of the initial pH of the medium for several reasons:

1. Buffering the medium to maintain a constant pH for the duration of the experiment is not possible in every case, since some molds produce considerable acid during growth.

2. The use of buffers in the medium would introduce ions or undissociated molecules, which might conceivably have a specific effect upon the growth of the organism.

3. Cereal products (foods in general) are not very highly buffered. The effect of the pH of bread on the growth of molds will be, for the most part, a function of the initial pH.

TABLE I

GROWTH OF *Rhizopus Nigricans* AS INFLUENCED BY INITIAL pH

Initial pH	24 hours		48 hours		72 hours	
	Dry matter	pH	Dry matter	pH	Dry matter	pH
	Mg.		*Mg.*		*Mg.*	
2.1	3	2.1	6	2.1	8	2.1
2.8	4	2.7	24	2.7	32	2.7
3.7	10	3.7	55	3.6	69	3.7
4.6	17	4.5	63	4.4	80	4.5
5.2	16	5.1	68	5.0	79	5.1
5.4	17	5.3	69	5.2	75	5.1
6.2	16	5.9	63	5.7	80	5.7
6.5	23	6.2	56	6.0	71	6.1

Table I shows the influence of the initial pH of the medium on the growth of *Rhizopus nigricans*, the mold which is commonly referred to by bakers as "whiskers."

The bread medium was set at different pH levels by means of concentrated hydrochloric acid and potassium hydroxide. Fifty cubic centimeter portions of the medium were then pipetted into 200 c.c. Erlenmeyer flasks. The flasks were then plugged with cotton and sterilized. After sterilization, each flask was inoculated with 1 c.c. of an aqueous suspension of spores of *Rhizopus nigricans*, and incubated at 30° C. At the time intervals indicated, the mold crops were harvested in triplicate by filtering through weighed alundum crucibles, washing with distilled water, and drying to constant weight at 105° C. pH measurements of the combined filtrates are shown for each harvest.

The results show no sharp optimum within the range of breadmaking. There is a definite inhibition of growth at pH 3.7 and below. There is an indicated optimum of *initial* growth (24 hours) at pH 6.5, but the growth optimum at 48 and 72 hours extends over the range from pH 4.6 to pH 6.2.

The influence of pH on the growth of other molds was investigated in connection with a study of the specific influence of acetic acid, which is discussed in Part III.

Experimental Procedure

Part II

The Specific Effect of Acids on the Growth of Some Common Molds

Having established, for *Aspergillus niger* and *Rhizopus nigricans*, that the pH optimum is not sharp but extends well over the entire range of breadmaking, the authors investigated the specific influence of certain acid substances, some of which are used to control rope in commercial breadmaking. Experiments with *Aspergillus niger* had shown that of these acid substances, acetic acid in particular has a marked specific influence on the growth of this organism. For example, complete inhibition of growth was obtained in bread medium set at pH 3.5, containing 0.2% acetic acid.

Experiments were set up which facilitated a study of the influence of these several acid substances, all at the same pH level, namely, 3.5.

Fifty cubic centimeter portions of the bread medium set at pH 3.5 were sterilized in 200 c.c. Erlenmeyer flasks. Standard solutions of the acid substances were made, and each likewise set at pH 3.5, by means of potassium hydroxide. After sterilization, these acid solutions at pH 3.5 were added in definite amounts to the culture medium, also at pH 3.5. After all flasks were adjusted to a volume of 60 c.c., they were inoculated with a suspension of spores of the particular mold under study, and incubated at 30° C. Since we were here only interested in determining which of these acids would completely prevent or greatly retard mold growth, the mold crops were not harvested. Observations were made at the end of two, three, and five days' incubation. Photographs taken at the end of the fifth day, as illustrated by Figures 1 to 8, show the relative effect of these different acid substances [2] on the growth of various molds.

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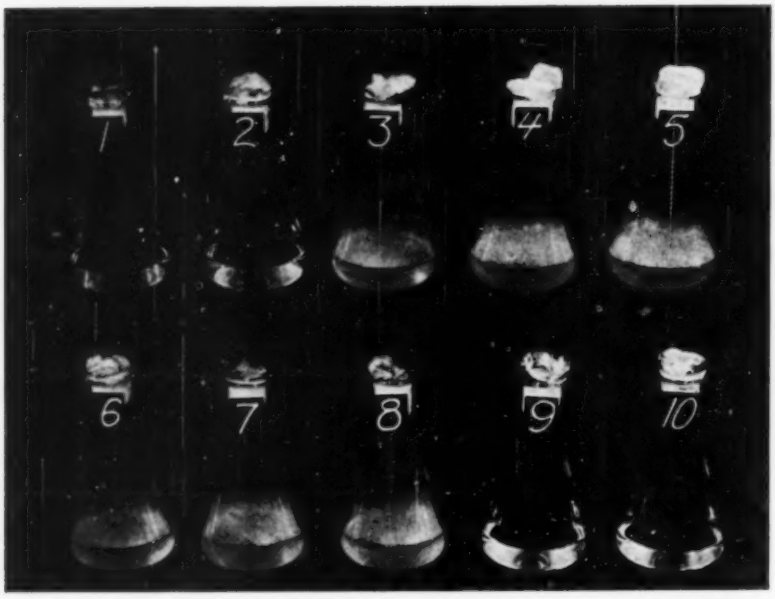
[2] The acid substances used were: acetic acid—Merck's Blue Label 99.5%; calcium acid phosphate—Eimer & Amend T.P.; citric acid—Eimer & Amend T.P.; lactic acid—Eimer & Amend C.P.; phosphoric acid—Mallinkrodt Analytical Reagent 85%; tartaric acid—Eimer & Amend T.P.; vinegar—Fleischmann 90-grain.

In no case, with the exception of acetic acid, is there any marked effect—either stimulation or inhibition of growth. Acetic acid, however, both in the form of the c.p. product and in the form of vinegar, has a very marked toxic effect upon these molds.

Further evidence on the effect of acetic acid was found by applying 90-grain vinegar to the outer surface of loaves of bread. The loaves were wiped or "painted" with vinegar, inoculated heavily with mold



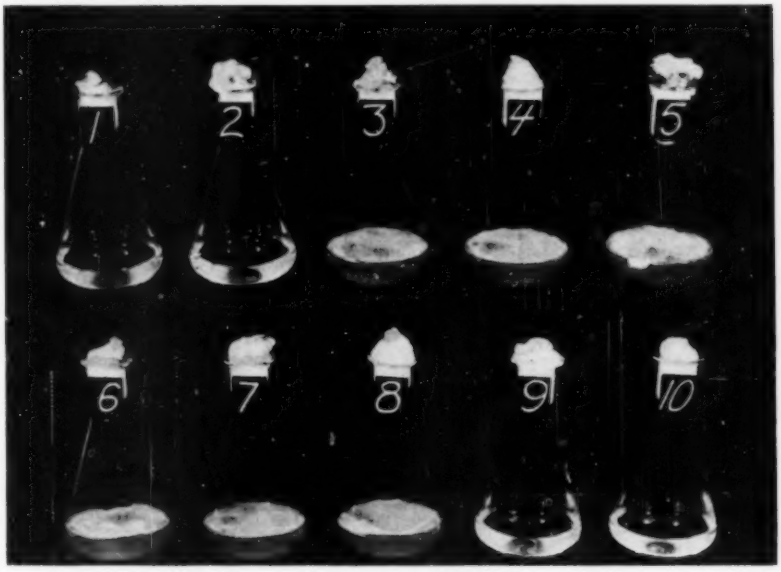
Rhizopus nigricans #8528

Figure 1. Effect of acids on the growth of *Rhizopus nigricans*.

Flask No.
1. 0.2% Acetic acid in form of c. p. acid.
2. 0.6% Acetic acid in form of c. p. acid.
3. 0.6% Calcium acid phosphate.
4. 0.6% Citric acid.
5. No added acid—control at pH 3.5.
6. 0.6% Lactic acid.
7. 0.6% Phosphoric acid.
8. 0.6% Tartaric acid.
9. 0.2% Acetic acid in form of 90-grain vinegar.
10. 0.6% Acetic acid in form of 90-grain vinegar.

spores, and stored in ordinary household bread boxes. Figure 9 clearly demonstrates the effectiveness of acetic acid in preventing the development of mold. One half of the loaf was wiped with a cloth which had been moistened with 90-grain vinegar; the other half received no treatment. Both halves were then inoculated with spores of *Rhizopus nigricans* and placed in a bread box inside a warm, moist chamber. The photograph was taken after five days of incubation.

The remarkably specific toxicity of acetic acid toward these molds seems to be a property of other fatty acids of this series. This is evident in the experimental series summarized in Table II, which shows the relative toxicity of propionic, acetic, *n*-butyric, iso-butyric, and maleic acid on *Aspergillus niger*, *Rhizopus nigricans*, and an unclassified green bread mold No. 9086. These acids were all compared at the same pH value, namely 3.5. The medium and experimental technique



Green bread mold #9086

Figure 2. Effect of acids on the growth of a green bread mold.

Flask No.
1. 0.2% Acetic acid in form of c. p. acid.
2. 0.6% Acetic acid in form of c. p. acid.
3. 0.6% Calcium acid phosphate.
4. 0.6% Citric acid.
5. No added acid—control at pH 3.5.
6. 0.6% Lactic acid.
7. 0.6% Phosphoric acid.
8. 0.6% Tartaric acid.
9. 0.2% Acetic acid in form of 90-grain vinegar.
10. 0.6% Acetic acid in form of 90-grain vinegar.

were the same as used in the experimental series preceding. It is to be noted that maleic acid is without significant influence on any of these molds. The saturated fatty acids, acetic, propionic, *n*-butyric, and iso-butyric were found to be very toxic to all three molds. Kiesel (1913) [3] showed that the saturated fatty acids and their halogen substitution products were more effective than strong mineral acids in preventing the growth of *Aspergillus niger* in Raulins solution.

[3] Kiesel, A. The action of different acids and acid salts upon the development of *Aspergillus niger*. Ann. inst. Pasteur **27**: 391–420 (1913).

TABLE II

RELATIVE EFFECT OF CERTAIN ORGANIC ACIDS ON THE GROWTH OF MOLDS AT pH 3.5

Acid concentration in medium	*Aspergillus niger*		Green mold No. 9086		*Rhizopus nigricans*	
	After 72 hours	After 230 hours	After 72 hours	After 230 hours	After 72 hours	After 230 hours
%						
0.5 Acetic	—	—	—	—	—	—
0.2 Acetic	tr	tr	—	—	—	—
0.1 Acetic	+++	+++	—	tr	—	—
0.05 Acetic	+++	+++	+	+++	++	+++
0.5 Propionic	—	—	—	—	—	—
0.2 Propionic	—	—	—	—	—	—
0.1 Propionic	—	tr	—	—	—	—
0.05 Propionic	++	+++	—	tr	tr	+
0.5 *n*-butyric	—	—	—	—	—	—
0.2 *n*-butyric	—	—	—	—	—	—
0.1 *n*-butyric	—	—	—	—	—	—
0.05 *n*-butyric	+	+++	tr	tr	tr	tr
0.5 iso-butyric	—	—	—	—	—	—
0.2 iso-butyric	—	tr	—	—	—	—
0.1 iso-butyric	+	+++	—	—	tr	tr
0.05 iso-butyric	+	+++	tr	+	tr	++
0.5 Maleic	+++	+++	tr	+++	++	+++
0.2 Maleic	+++	+++	+	+++	+++	+++
Control	+++	+++	+	+++	+++	+++

Key: — No growth.
tr Trace of growth.
+ Little growth.
++ Medium growth.
+++ Heavy growth.

PART III

The Influence of Hydrogen-ion Concentration and Acetic Acid on the Growth of Some Common Molds

The purpose of the following experiments was to determine if the conclusions, regarding the effects of hydrogen-ion concentration and acetic acid on the growth of *Aspergillus niger*, may be considered as applying to bread molds in general.

Accordingly the investigations were extended to include four other molds, *Aspergillus fumigatus*, *Neurospora sitophila*, *Rhizopus nigricans*, and a green mold isolated from a loaf of commercial bread. The technique [4] was the same as described in Part I except that acetic acid

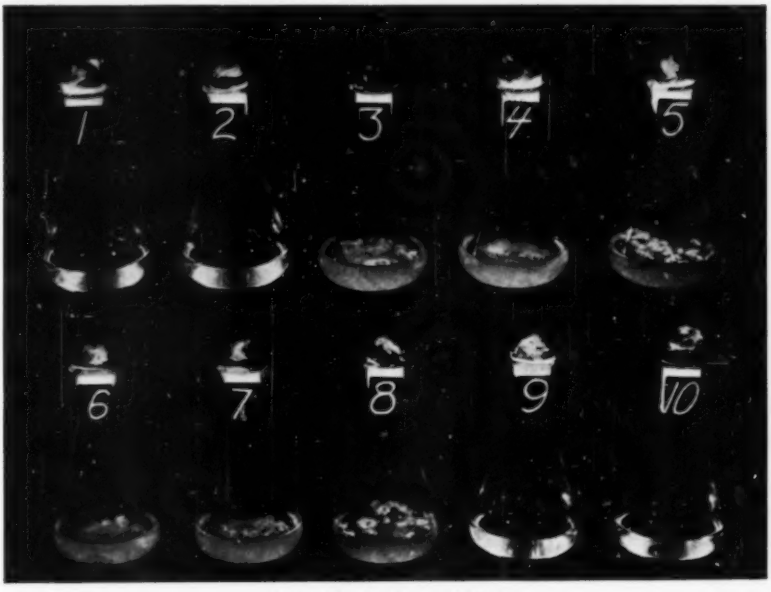
[4] For detailed description see Cereal Chemistry **12**, 249 and 250 (1935).

solutions set at definite pH levels were added to some of the flasks which contained bread medium at corresponding pH levels.

Table III shows the results obtained with the mold *Aspergillus fumigatus*.

In the absence of acetic acid:

1. At 24 hours, there is no definite optimum with respect to pH alone.



Aspergillus fumigatus #8526

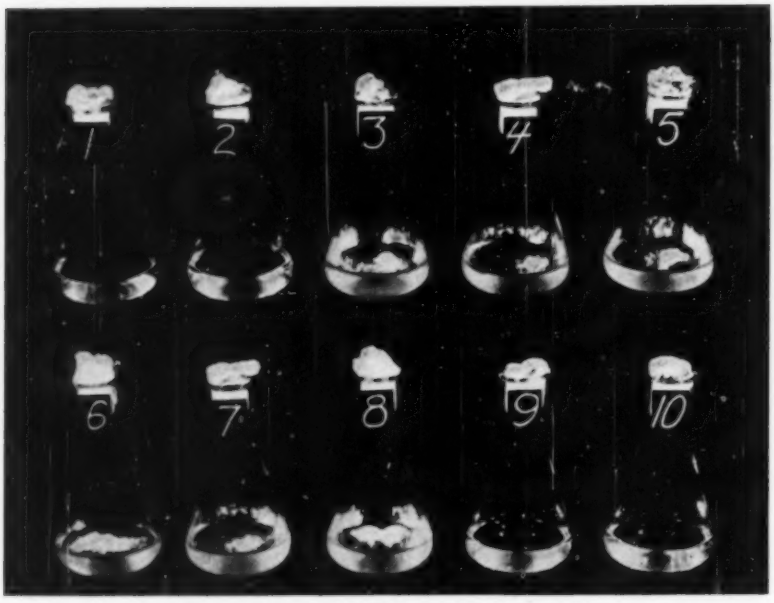
Figure 3. Effect of acids on the growth of *Aspergillus fumigatus*.

Flask No.
1. 0.2% Acetic acid in form of c. p. acid.
2. 0.6% Acetic acid in form of c. p. acid.
3. 0.6% Calcium acid phosphate.
4. 0.6% Citric acid.
5. No added acid—control at pH 3.5.
6. 0.6% Lactic acid.
7. 0.6% Phosphoric acid.
8. 0.6% Tartaric acid.
9. 0.2% Acetic acid in form of 90-grain vinegar.
10. 0.6% Acetic acid in form of 90-grain vinegar.

2. At 48 hours, an optimum is indicated at pH 5.0 to 5.4. However, there is a question as to whether these differences are large enough to be of any practical significance.

3. At 72 hours, the optimum would seem to be definitely below pH 5.8.

4. At 96 hours, a definite optimum is indicated at pH 4.5.



Neurospora sitophila #8522

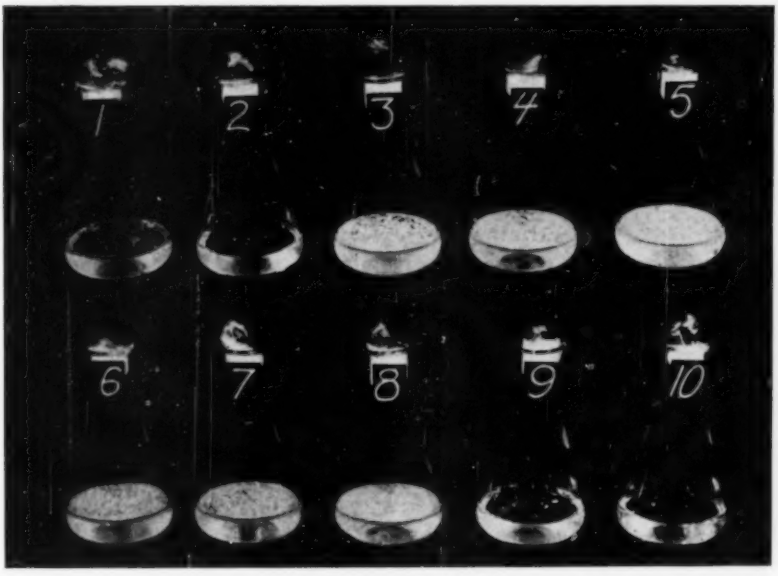
Figure 4. Effect of acids on the growth of *Neurospora sitophila*.

Flask No.
1. 0.2% Acetic acid in form of c. p. acid.
2. 0.6% Acetic acid in form of c. p. acid.
3. 0.6% Calcium acid phosphate.
4. 0.6% Citric acid.
5. No added acid—control at pH 3.5.
6. 0.6% Lactic acid.
7. 0.6% Phosphoric acid.
8. 0.6% Tartaric acid.
9. 0.2% Acetic acid in form of 90-grain vinegar.
10. 0.6% Acetic acid in form of 90-grain vinegar.

TABLE III

GROWTH OF *Aspergillus Fumigatus* AS INFLUENCED BY INITIAL pH AND ACETIC ACID

Initial pH	"Acetic acid"	24 hours		48 hours		72 hours		96 hours	
		Dry matter	pH	Dry matter	pH	Dry matter	pH	Dry matter	pH
	%	*Mg.*		*Mg.*		*Mg.*		*Mg.*	
4.5	0	7	4.4	65	4.3	120	4.1	148	3.8
4.5	0.2	2	4.4	8	4.5	77	4.7	111	4.6
4.5	0.4	1	4.4	2	4.5				
5.0	0	8	4.8	75	4.7	113	4.1	139	4.0
4.9	0.2	3	4.8	49	5.2	113	5.1	143	4.6
4.9	0.4	3	4.8	32	5.1				
5.4	0	8	5.3	64	4.8	117	4.3	140	4.1
5.4	0.2	5	5.3	72	5.4	129	5.2	149	4.8
5.4	0.4	3	5.3	48	5.5				
5.8	0	7	5.7	67	4.9	110	4.4	135	4.1
5.8	0.2	6	5.9	68	5.6	122	5.3	146	5.0
5.8	0.4	5	5.9	66	5.8				



Aspergillus oryzae #8501

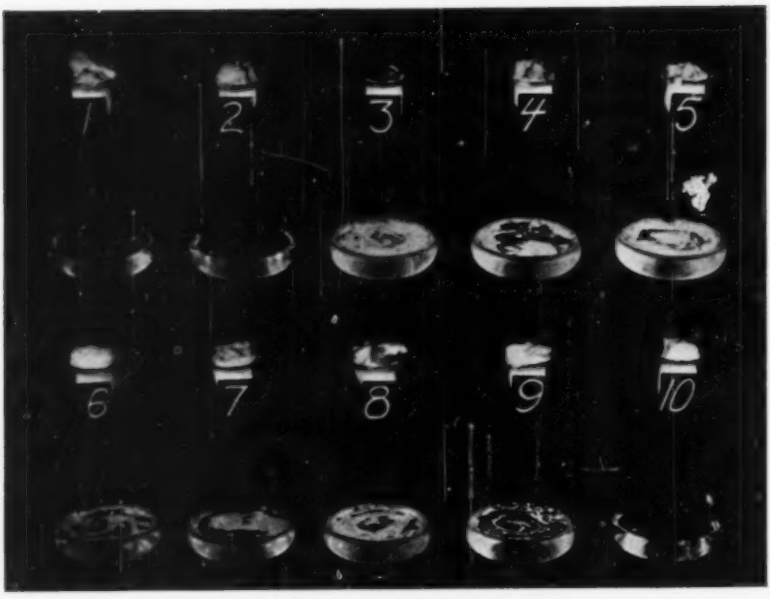
Figure 5. Effect of acids on the growth of *Aspergillus oryzae*.

Flask No.
1. 0.2% Acetic acid in form of c. p. acid.
2. 0.6% Acetic acid in form of c. p. acid.
3. 0.6% Calcium acid phosphate.
4. 0.6% Citric acid.
5. No added acid—control at pH 3.5.
6. 0.6% Lactic acid.
7. 0.6% Phosphoric acid.
8. 0.6% Tartaric acid.
9. 0.2% Acetic acid in form of 90-grain vinegar.
10. 0.6% Acetic acid in form of 90-grain vinegar.

TABLE IV

GROWTH OF *Neurospora Sitophila* AS INFLUENCED BY INITIAL pH AND ACETIC ACID

Initial pH	"Acetic acid"	24 hours		48 hours		72 hours		96 hours	
		Dry matter	pH	Dry matter	pH	Dry matter	pH	Dry matter	pH
	%	*Mg.*		*Mg.*		*Mg.*		*Mg.*	
4.5	0	9	4.6	52	5.0	76	5.5	99	5.9
4.5	0.2	2	4.6	32	5.0	77	5.9	105	6.7
4.5	0.4					9	4.7		
5.1	0	10	5.0	51	5.4	81	5.7	103	6.1
5.0	0.2	3	5.0	40	5.6	79	6.6	106	6.8
5.0	0.4					81	6.4		
5.5	0	10	5.5	53	5.8	80	6.2	104	6.3
5.3	0.2	7	5.3	53	6.1	85	6.8	108	6.8
5.5	0.4					83	7.1		
6.1	0	12	5.9	55	4.8	82	6.5	105	4.3
6.0	0.2	10	6.0	57	6.6	83	7.2	107	7.0
6.0	0.4					89	7.6		



P. luteum-purpurogenum #8506

Figure 6. Effect of acids on the growth of *P. luteum-purpurogenum*.

Flask No. 1. 0.2% Acetic acid in form of c. p. acid.
2. 0.6% Acetic acid in form of c. p. acid.
3. 0.6% Calcim acid phosphate.
4. 0.6% Citric acid.
5. No added acid—control at pH 3.5.
6. 0.6% Lactic acid.
7. 0.6% Phosphoric acid.
8. 0.6% Tartaric acid.
9. 0.2% Acetic acid in form of 90-grain vinegar.
10. 0.6% Acetic acid in form of 90-grain vinegar.

TABLE V

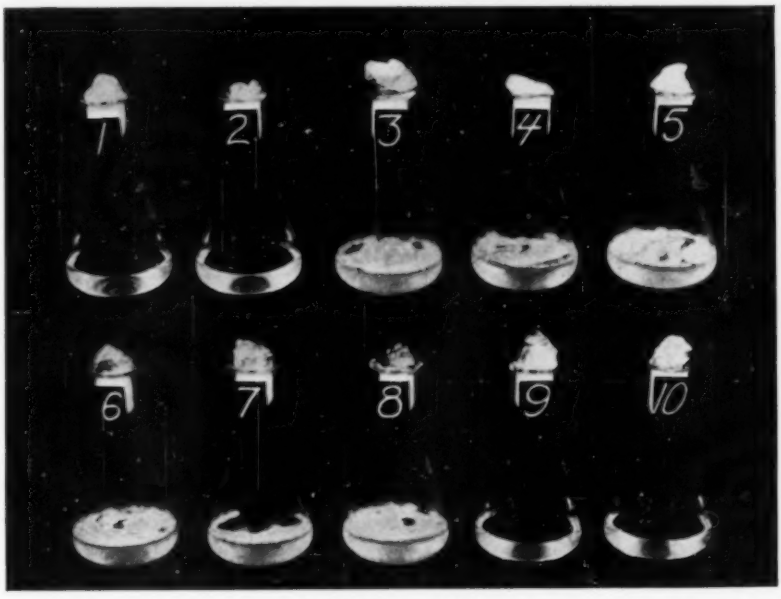
GROWTH OF GREEN BREAD MOLD NO. 9086 AS INFLUENCED BY INITIAL pH AND ACETIC ACID

Initial pH	"Acetic acid"	45 hours		69 hours		93 hours	
		Dry matter	pH	Dry matter	pH	Dry matter	pH
	%	*Mg.*		*Mg.*		*Mg.*	
4.5	0	13	4.6	20	4.6	46	4.7
4.5	0.2	No growth	4.5	Trace	4.5	6	4.5
4.5	0.4	No growth	4.5	No growth	4.5	No growth	4.5
5.1	0	14	5.0	18	5.1	47	5.1
5.0	0.2	3	4.9	9	5.0	11	5.0
5.0	0.4	No growth	5.0	No growth	5.0	No growth	5.0
5.5	0	13	5.4	19	5.1	41	5.0
5.4	0.2	8	5.3	15	5.4	38	5.5
5.4	0.4	6	5.3	9	5.4	26	5.4
5.9	0	15	5.4	21	5.8	36	5.1
5.9	0.2	12	5.8	16	5.9	45	5.8
5.8	0.4	8	5.8	13	5.9	41	5.8

In the presence of acetic acid:

1. At 24 and 48 hours, the growth of this mold is definitely inhibited at all pH levels below pH 5.8 by 0.4% acetic acid, and by 0.2% acetic acid at pH 5.0 and below.

2. At 72 and 96 hours, 0.2% acetic acid greatly inhibited growth at pH 4.5, was without effect at pH 5.0, and actually was slightly stimulating to growth at pH 5.4 and 5.8.



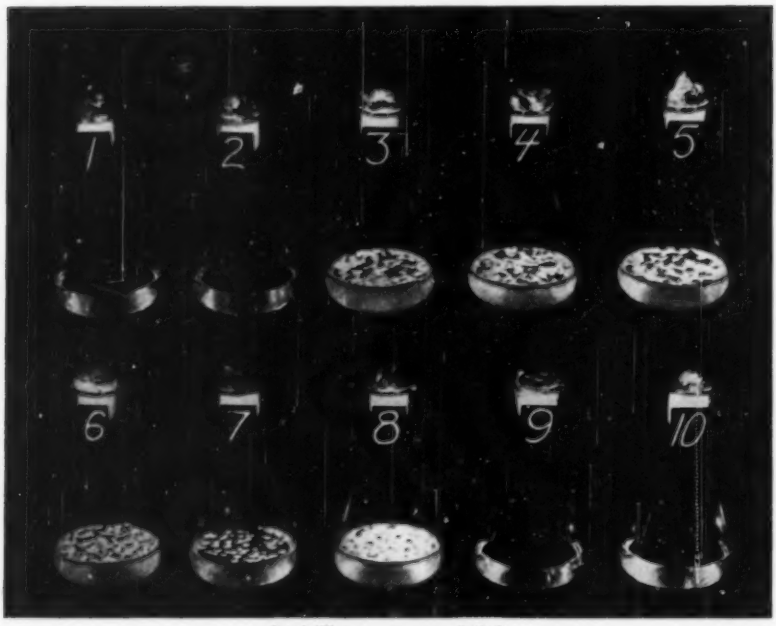
Aspergillus flavus #8524

Figure 7. Effect of acids on the growth of *Aspergillus flavus*.

Flask No.
1. 0.2% Acetic acid in form of c. p. acid.
2. 0.6% Acetic acid in form of c. p. acid.
3. 0.6% Calcium acid phosphate.
4. 0.6% Citric acid.
5. No added acid—control at pH 3.5.
6. 0.6% Lactic acid.
7. 0.6% Phosphoric acid.
8. 0.6% Tartaric acid.
9. 0.2% Acetic acid in form of 90-grain vinegar.
10. 0.6% Acetic acid in form of 90-grain vinegar.

Table IV records data on *Neurospora sitophila*, a pink mold found on bread.

In this experiment no sharp optimum was found, with respect to pH alone, at any stage of growth. There is further evidence of the strong inhibiting effect of acetic acid on the initial stages of growth at pH levels below 5.5. At pH 5.5 and 6.0, acetic acid does not appreciably influence the growth of this mold.



Penicillium expansum #8527

Figure 8. Effect of acids on the growth of *Penicillium expansum*.

Flask No. 1. 0.2% Acetic acid in form of c. p. acid.
2. 0.6% Acetic acid in form of c. p. acid.
3. 0.6% Calcium acid phosphate.
4. 0.6% Citric acid.
5. No added acid—control at pH 3.5.
6. 0.6% Lactic acid.
7. 0.6% Phosphoric acid.
8. 0.6% Tartaric acid.
9. 0.2% Acetic acid in form of 90-grain vinegar.
10. 0.6% Acetic acid in form of 90-grain vinegar.

TABLE VI

GROWTH OF *Rhizopus Nigricans* AS INFLUENCED BY INITIAL pH AND ACETIC ACID

Initial pH	"Acetic acid"	24 hours		48 hours		72 hours		96 hours	
		Dry matter	pH	Dry matter	pH	Dry matter	pH	Dry matter	pH
		Mg.		*Mg.*		*Mg.*		*Mg.*	
4.6	0	19	4.5	64	4.5	74	4.5	86	4.8
4.6	0.2%	No growth	4.5	No growth	4.6	Trace	4.6	Trace	4.6
4.5	0.4%	No growth	4.5	No growth	4.5	No growth	4.5	No growth	4.5
5.1	0	17	5.1	62	5.0	76	5.1	86	5.2
5.0	0.2%	13	5.0	22	5.1	35	5.2	52	5.6
5.0	0.4%	No growth	5.0	No growth	5.0	Trace	5.0	Trace	5.0
5.5	0	20	5.4	63	5.3	77	5.3	89	5.3
5.3	0.2%	14	5.3	29	5.3	53	5.8	64	6.5
5.4	0.4%	9	5.4	25	5.3	46	5.8	59	6.5
6.0	0	23	5.7	65	5.6	71	5.5	87	5.5
6.0	0.2%	19	5.8	51	6.3	63	6.7	72	7.0
6.0	0.4%	16	5.9	41	6.2	60	6.7	65	7.2

The data in Table V were obtained with an unclassified mold—a common green mold isolated from a commercial loaf of bread.

The following conclusions may be drawn from this experiment:

With respect to the effect of H-ion concentration alone, the initial stages of growth (at 24 and 69 hours) are practically the same at all pH levels from 4.5 to about 6.0. However, at 93 hours, there is slightly more mold growth at pH 4.5 and 5.0 than at pH 5.4 and 5.8.

The inhibiting action of acetic acid on the initial stages of growth is evident, being very effective within the pH range where one must work to control rope.

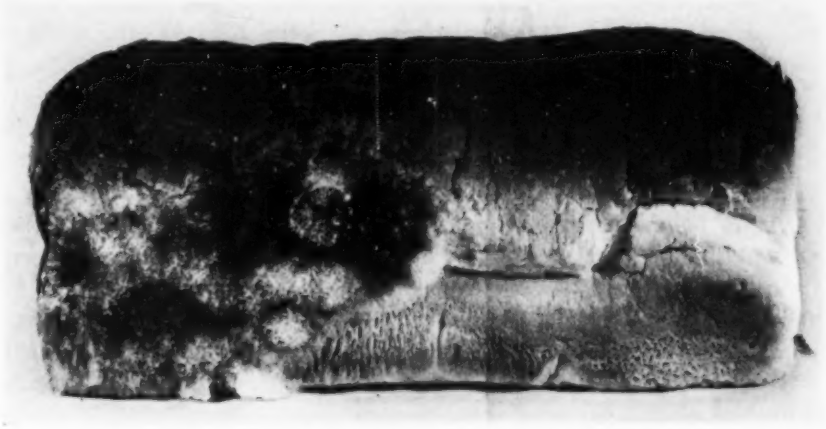


Figure 9. Effect of vinegar in retarding the growth of bread molds.

At a pH in the neighborhood of 6, acetic acid inhibited initial stages of growth, yet the growth at 93 hours is slightly higher in the presence of this acid.

Table VI shows data obtained with *Rhizopus nigricans*. These results may be summarized as follows:

In the absence of acetic acid, the growth of this mold at all stages is practically the same over the pH range of 4.5 to 6.0.

Acetic acid in concentrations of 0.2 and 0.4% inhibits the growth of this mold over the pH range of 4.5 to 6.0.

Summary

In these investigations, five typical bread molds representing those frequently found on bread were studied. The results may be summarized as follows:

The effect of acidity on the growth of bread molds must be considered not only from the standpoint of hydrogen-ion concentration

but from the specific effect of the kind of acid used. At the same hydrogen-ion concentration different acids may vary considerably in their effect. Fatty acids are much more toxic to molds than mineral acids and such organic acids as lactic, citric, tartaric, and maleic.

Molds, like yeasts, have a very wide growth optimum with respect to hydrogen-ion concentration. They seem to grow equally well at all hydrogen-ion concentrations within which commercial bread is produced.

Acetic acid, either in c.p. form or in the form of vinegar, has a marked influence on the growth of bread molds. Similar activity is shown by formic, propionic and butyric acids.

The effect of acetic acid at fixed concentration is a function of the pH of the medium. At low pH values acetic acid is very toxic to molds.

At high pH values, 5.5 to 6.0, acetic acid retards the initial growth of the molds studied and was found to have only a slight effect on the ultimate growth of these molds—an effect varying from slight inhibition to slight stimulation.

It is believed the data obtained in these investigations rather definitely show that no matter what acid or acid salt the baker used, by increasing the acidity of bread to the neighborhood of pH 5.0 for the purpose of controlling rope, he would not increase his mold problem; and if the acid used were acetic acid or other innocuous fatty acid of this series, one might expect not only control of rope but also some retardation of the development of mold on such bread.

A film of dilute acetic acid, such as vinegar, covering the surface of a loaf of bread, is very effective in preventing or retarding the development of mold.

It is believed these findings and conclusions may apply to a wide variety of products other than food and bakery products.

SOME OBSERVATIONS ON THE STUDY OF VARIETAL DIFFERENCES IN THE MALTING QUALITY OF BARLEY [1]

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(Read at the Annual Meeting, May 1937)

The investigation reported in this paper was undertaken with the object of obtaining preliminary information on the relative importance of three factors which affect the study of varietal differences in the malting quality of barley. These factors are: (1) the precision of the malting test, (2) the differential effect of malting tests on varieties and (3) the differential effect of environment on varieties.

Materials and Methods

Four varieties of barley, O.A.C. 21, Wisconsin Ped. 38, Peatland, and Hannchen, were grown at four widely separated experimental stations: Nappan, Nova Scotia; Ste. Anne de la Pocatière, Quebec; Ottawa, Ontario; and Indian Head, Saskatchewan. From the sixteen samples thus obtained, duplicate malts were made by each of four different experimental methods, namely, the cage method used in conjunction with a Saladin system by the Canada Malting Company, Ltd., Montreal; the stocking method used in conjunction with a drum system by the Dominion Malting Company, Ltd., Winnipeg; the laboratory method used at the University of Manitoba (Anderson and Rowland, 1937); and the laboratory method used in the National Research Laboratories, Ottawa (Anderson, 1937).

The samples of barley were prepared in the National Research Laboratories with the aid of a Boerner sampler and each was adjusted to a weight equivalent to 250 g. of barley dry matter. The samples for each test were selected at random and were subsequently arranged in random order within sets of first and second replicates. In each laboratory the malts were made in order in batches of four. The batches were started at intervals of three or four days. Thus the malts were made in random order and with duplicate malts in different batches.

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[1] Published as paper No. 124 of the Associate Committee on Grain Research of the National Research Council of Canada and the Dominion Department of Agriculture.

The finished malts were weighed and returned in sealed cans to the National Research Laboratories where they were analyzed in random order within sets from different laboratories. Determinations of fine-grind extract, coarse-grind extract, moisture and color were made by the Official Methods of the American Society of Brewing Chemists (1936). Diastatic power was determined by the modification of the Official Method proposed by Anderson and Sallans (1937). In determining permanently soluble nitrogen, 50 ml. of wort (Official Method, fine-grind) were buffered to pH 5.2, heated for 30 minutes in a boiling water bath and filtered, and the nitrogen in 25 ml. of the filtrate determined. The permanently soluble nitrogen is reported as per cent of wort solids. Growth counts were made by estimating the length of the acrospires for 100 kernels in tenths of the kernel length and the mean is reported as per cent of kernel length. Malt yield was calculated from the weights of the samples before and after malting and is reported on a dry basis.

The index of protein modification was calculated in the usual way by dividing the percentage of permanently soluble nitrogen in the malt by the percentage of nitrogen in the barley. A second index of modification, which has been widely used in Europe, is also reported. This has been called "index of modification by grinding." It is determined by subtracting the coarse-grind extract from the fine-grind extract.

Results and Discussion

Statistical treatment: The variance of the data for each determination was analyzed into portions due to: (1) average differences between varieties; (2) average differences between experimental stations; (3) average differences between malting tests; (4) differences in the relative performance of the varieties at different stations; (5) differences in the relative performance of the 16 samples (four varieties from each of four stations) in different tests; and (6) differences between duplicate malts. The results of the analyses of variance are reported in Table I.

The propriety of combining for analyses the results of four tests which differed in precision may be questioned. However, as the precision of the tests was by no means a limiting source of error in the investigation, the procedure was considered to be legitimate.

Precision of the tests: The standard errors of the means of single analyses of duplicate malts, for each determination and each malting test, are given in Table II. Each figure is calculated from 16 pairs of data and must, therefore, be considered only as a rough estimate of the standard error.

Bearing in mind that the investigation of precision was made as rigorous as possible by requiring duplicate malts to be made in different

batches, and that only single analyses were made on each malt, it appears that all tests attained a very useful level of precision. The data presented in Table I show that precision as a source of error in the comparison of the malting quality of varieties was greatly exceeded both by the differential effects of tests on samples and of stations on varieties. The results of the investigation, therefore, suggest that,

TABLE I

ANALYSES OF VARIANCE OF ANALYTICAL DATA ON MALTS FROM FOUR MALTING TESTS MADE ON FOUR VARIETIES OF BARLEY GROWN AT FOUR EXPERIMENTAL STATIONS

Variation due to	Degrees of freedom	Mean squares							
		Extract, fine-grind	Extract, coarse-grind	Diastatic power	Permanently soluble nitrogen	Growth	Malt yield	Index of protein modification	Index of modification by grinding
		%	%	°L.	%	%	%		
Varieties	3	226.66**	204.27**	9,042	0.4870**	794*	3.58	651.1**	5.74**
Stations	3	178.59**	189.84**	64,194**	1.3670**	907*	53.10**	773.8**	1.67
Tests	3	33.17††	32.89††	21,600††	0.1841††	3,570††	117.88††	336.9††	2.32††
Varieties ×stations	9	12.01††	13.60††	3,245††	0.0663††	170	3.22††	67.1††	0.57†
Tests ×samples	45	1.09‡‡	1.57‡‡	227‡‡	0.0030‡‡	86‡‡	0.71	3.8‡‡	0.21‡
Duplicates	64	0.15	0.30	54	0.0011	29	0.68	1.8	0.13

* and ** significantly greater than the mean square due to varieties × stations.
† and †† significantly greater than the mean square due to tests × samples.
‡ and ‡‡ significantly greater than the mean square due to duplicate malting tests.
Note: In this and later tables, double signs indicate that a 1% level of significance is attained and single signs that a 5% level is attained.

TABLE II

PRECISION OF TESTS

Standard Errors of Means of Single Analyses of Duplicate Malts

Determination	Test 1[1]	Test 2	Test 3	Test 4
Extract, fine-grind, %	0.16	0.46	0.14	0.22
Extract, coarse-grind, %	0.30	0.58	0.33	0.25
Moisture, %	0.11	0.10	0.49	0.11
Diastatic power, °L.	5.2	3.2	4.9[2]	1.8
Permanently soluble nitrogen as % of wort solids	0.02	0.03	0.03	0.02
Growth, %	3.7	3.9	4.1	3.6
Malt yield, %	0.33	0.66	0.45	0.80
Index of protein modification	0.8	1.3	0.9	0.7
Index of modification by grinding	0.25	0.37	0.24	0.24

[1] It is not considered advisable or necessary to state which test was made in each laboratory.
[2] Partially corrected for differences in the kilning of different batches, by means of an analysis of variance and covariance of the data on diastatic power and moisture.

with respect to the more important determinations, the level of precision attained in the tests is adequate for most investigations which are likely to be undertaken with them.

Differential effect of tests on samples: One of the objects of the investigation was to find out whether the samples would be placed in the same order with respect to any malt quality when the malts were

made by different methods. In this connection it is first necessary to determine whether the four tests used in the investigation differed. This can be determined in a general way by comparing the characteristics of the malts made in each test by means of the data presented in Table III which represent the mean values, over all samples, for each determination and each test.

The data show that the tests differed perhaps as widely as could be expected when it is borne in mind that all tests involved a six-day germination period. Test 1 is characterized by low extract and index of protein modification, together with high yield and reasonably high growth. In test 2 a higher extract yield and index of protein modification were obtained with about the same growth but with much lower malt yield. Test 3 shows high extract yield combined with the lowest growth, a medium degree of protein modification and a high

TABLE III

MEANS, OVER 32 MALTS, FOR EACH MALTING TEST

Determination	Test 1	Test 2	Test 3	Test 4	Necessary difference
Extract, fine-grind, %	74.4	76.0	76.4	76.5	0.52
Extract, coarse-grind, %	73.0	74.6	74.6	75.4	0.62
Moisture, %	3.8	3.8	5.2	5.0	0.18
Color, Lovibond units	1.4	1.4	1.4	1.2	0.04
Diastatic power, °L	100	119	143	159	7.5
Permanently soluble nitrogen as % of wort solids	0.96	1.12	1.07	1.12	0.03
Malt yield, %	93.5	89.6	93.5	92.3	0.4
Index of protein modification	34.8	41.6	39.7	41.8	1.0
Growth, %	79	76	60	84	4.6
Index of modification by grinding	1.4	1.4	1.8	1.1	0.23

malt yield. The malts made in test 4 were the best grown and best modified as shown by both indices of modification. They also yielded the highest extract. The wide differences in the diastatic power of the four sets of malts are probably caused largely by differences in the kilning which are also reflected in the data for moisture. It is interesting to note that there are indications that growth and index of modification by grinding are fairly closely associated but that there is no apparent relationship between these characters and index of protein modification or malt yield.

The differences between the tests were sufficiently large to show that a significant interaction exists between samples and malting method. The tests did not place all samples in exactly the same order. Reference to Table I will show that the mean square due to the interaction of tests and samples was significantly greater than that due to dupli-

cates for all determinations listed, except malting loss. Further information with respect to the two most important determinations is given in Table IV, in which the positions of the samples in each test are shown. With respect to extract, there were three cases in which a sample was displaced to an extent equivalent to over 1%, and with respect to diastatic power, three samples were displaced to an extent equivalent to over 12° Lintner. In general, however, it is apparent that all tests placed the samples in much the same order.

The discrepancies between tests are considerably reduced when the comparison is confined to the means for each variety over all four stations. Data representing these means, for fine-grind extract,

TABLE IV

RELATIVE POSITIONS OF SAMPLES FOR EACH TEST FOR EXTRACT AND DIASTATIC POWER

Extract, fine-grind, %								Diastatic power, °L.							
Samples		Tests					Mean extract, %	Samples		Tests					Mean diastatic power, °L.
Station	Variety	1	2	3	4	Mean		Station	Variety	1	2	3	4	Mean	
Nappan	Hannchen	1	1	1	1	1	82.4	Indian Head	Peatland	1	1	1	1	1	224
St. Anne	Hannchen	3	2	2	2	2	80.1	Indian Head	O.A.C. 21	2	2	2	2	2	191
Nappan	Peatland	2	3	3	3	3	78.9	Ottawa	Peatland	4	3	4	3	3	176
Nappan	O.A.C. 21	4	5	4	4	4	78.2	Ottawa	O.A.C. 21	5	5	3	6[2]	4	165
Indian Head	Hannchen	5	6	5	5	5	77.6	Indian Head	Wis.P. 38	3[2]	4	5	5	5	161
St. Anne	Peatland	6	4	6	6	6	77.3	Ottawa	Hannchen	8	6	6	4[2]	6	148
St. Anne	O.A.C. 21	7	7	8	10	7	76.0	Indian Head	Hannchen	6	8	8	7	7	138
Ottawa	O.A.C. 21	8	10	7	8	8	75.7	St. Anne	O.A.C. 21	9	9	7	9	8	136
Ottawa	Hannchen	11	8	8	7	9	75.7	Ottawa	Wis.P. 38	7	7	9	8	9	135
Nappan	Wis.P. 38	8	9	11	9	10	75.6	St. Anne	Hannchen	11	10	10	10	10	109
Ottawa	Peatland	10	11	10	11	11	75.4	St. Anne	Peatland	10	11	11	11	11	104
Indian Head	O.A.C. 21	12	12	13[1]	12	12	74.7	Nappan	Hannchen	12	12	13	12	12	91
St. Anne	Wis. P. 38	16[1]	13	12[1]	13	13	73.2	Nappan	O.A.C. 21	13	13	15	14	13	82
Indian Head	Peatland	13	14	14	14	14	71.6	St. Anne	Wis.P. 38	16	14	13	13	14	78
Ottawa	Wis.P. 38	14	15	15	15	15	71.0	Nappan	Peatland	14	16	12[2]	15	15	78
Indian Head	Wis.P. 38	15	16	16	16	16	69.9	Nappan	Wis.P. 38	15	15	16	16	16	70

[1] Samples transposed more than 1%.
[2] Samples transposed more than 12°L.

diastatic power, index of protein modification and growth, are presented graphically in the form of histograms in Figure 1. A study of the graphs will show that, although an interaction effect exists between varieties and tests, it does not constitute a serious source of error.

Differential effect of environment on varieties: That the four experimental stations at which the samples were grown represent different environments is obvious from their geographic positions, and the effect is well illustrated by the characteristics of the barley produced at each station. Data for the nitrogen content and 1,000-kernel weight of the barleys are presented in Table V. It will be noted that the mean nitrogen content increases from 1.48% at Nappan to 2.70% at Indian

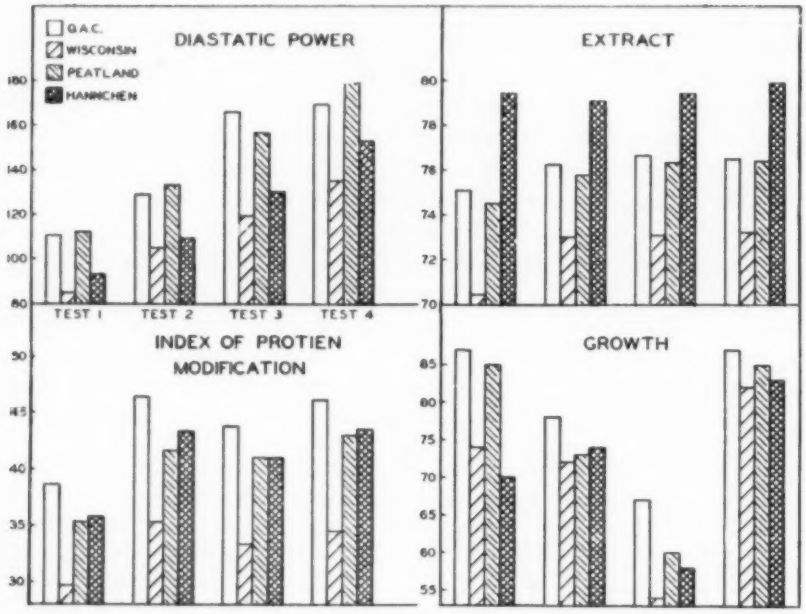

Figure 1. Histograms illustrating the magnitude of the differential effect of malting tests on varieties.

TABLE V

NITROGEN CONTENT AND 1000-KERNEL WEIGHT OF BARLEY SAMPLES

Variety	Stations				Mean
	Nappan	St. Anne	Ottawa	Indian Head	
	Nitrogen content, %				
O.A.C. 21	1.39	1.95	2.25	2.51	2.02
Wisconsin 38	1.43	1.64	2.38	2.77	2.06
Peatland	1.60	1.86	2.56	3.15	2.29
Hannchen	1.49	1.59	2.51	2.35	1.98
Mean	1.48	1.76	2.42	2.70	2.09
	1000-kernel weight, g.				
O.A.C. 21	31.9	35.5	33.4	30.4	32.8
Wisconsin 38	33.8	36.5	35.3	33.2	34.7
Peatland	31.6	30.7	30.6	27.6	30.1
Hannchen	40.0	36.2	40.2	35.1	37.9
Mean	34.3	34.7	34.9	31.6	33.9

Head. This represents a far wider range of nitrogen content than that considered suitable for malting in Canada. However, the stations were chosen with the object of obtaining a wide range in order to provide opportunity for the study of the differential effect of environment on varieties.

That the environment had a differential effect on the malting quality of the varieties is shown by the statistics given in Table I. The mean square due to the interaction of stations on varieties is significantly greater than that due to the interaction of tests on samples, for each determination except growth. For the purposes of this com-

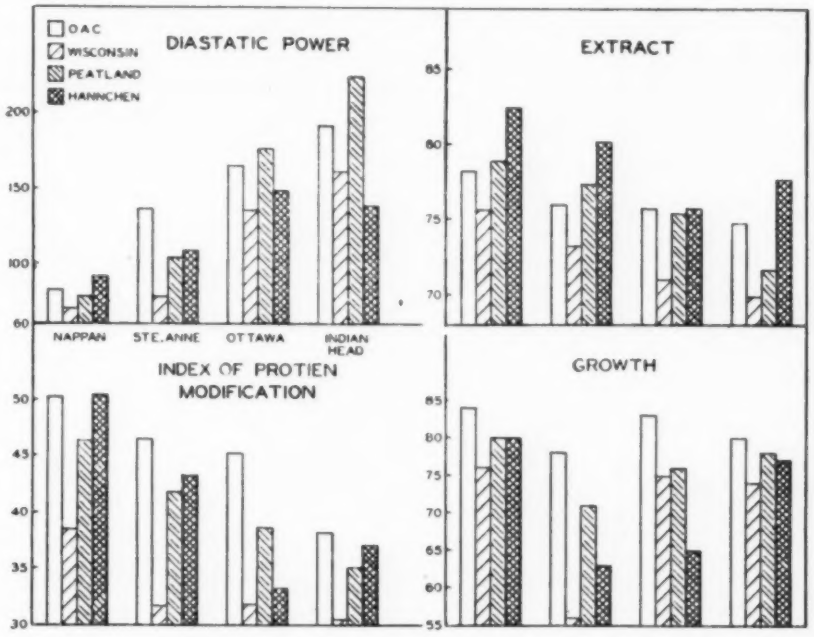

Figure 2. Histograms illustrating the magnitude of the differential effect of environment on varieties.

parison, the mean square due to the interaction of tests on samples is considered a better estimate of the experimental error of the investigation than the mean square for duplicates.

The differential effect of environment on the malting quality of the varieties is also illustrated by the histograms in Figure 2. Data for fine-grind extract, diastatic power, index of protein modification and growth are represented. The columns in each histogram represent the varieties and separate histograms represent the results obtained for each station. It will be noted that the interaction effect is considerably greater for diastatic power than for the other characteristics.

Comparison of varieties: Since the varieties were not placed in exactly the same relative positions at all stations, it is apparent that if varieties are to be compared over the full range of environments tested, it is first necessary to determine whether the mean square due to varieties is significantly greater than that due to the interaction between varieties and stations. Reference to Table I will show that this proved to be true for all determinations except diastatic power and malt yield. Thus, although the investigation is limited it serves to support the findings of European investigators who have shown that extract yield, percentage of permanently soluble nitrogen in the wort, and ease of modification are varietal characteristics. A review of earlier investigations of the effect of variety on malting quality is given by Hopkins and Krause (1937).

In Table VI there are given the mean values, over all stations and

TABLE VI

MEAN, OVER ALL STATIONS AND ALL TESTS, FOR EACH VARIETY

Determination	O.A.C. 21	Wis. P. 38	Peat-land	Hannchen	Necessary difference
Extract, fine-grind, %	76.1	72.4	75.8	78.9	1.7
Extract, coarse-grind, %	75.2	70.9	74.5	76.9	1.8
Moisture, %	4.4	4.5	4.3	4.6	0.7
Color, Lovibond units	1.42	1.27	1.38	1.37	0.06
Diastatic power, °L	144	111	145	121	28
Permanently soluble nitrogen as % of wort solids	1.15	0.93	1.19	1.0	0.13
Growth, %	81	70	76	71	6.5
Malt yield, %	92.1	92.7	92.0	92.5	0.9
Index of protein modification	43.7	33.1	40.2	40.9	4.1
Index of modification by grinding	0.9	1.5	1.3	2.0	0.4

tests, for each variety and each determination, together with the necessary differences required for a 5% level of significance. The latter values were calculated from the mean squares due to the interaction between varieties and stations.

O.A.C. 21, which is the standard malting variety in Canada, is characterized by high extract and permanently soluble nitrogen, together with good growth and ready modification. Peatland, which is also admitted to the malting grades, is very similar in character to O.A.C. 21 but does not modify quite so readily, probably because of its higher nitrogen content. (See Table V.) Wisconsin 38, a smooth-awned variety which Canadian maltsters consider entirely unsuited for their purpose, is low in extract and permanently soluble nitrogen and its growth and modification are poor. Hannchen, the only two-rowed variety represented, is high in extract yield, as might be ex-

pected because of its higher 1,000-kernel weight and lower nitrogen content, but its growth and physical modification are comparatively poor. It appears that this variety is not well suited to a six-day germination period.

Because of the magnitude of the interaction between varieties and stations with respect to diastatic power, the data for this determination show only that the poor malting variety, Wisconsin 38, is inferior in production of diastase to the better malting varieties, O.A.C. 21 and Peatland. This fact can be verified by comparison of the results obtained at individual stations which are presented graphically in Figure 2.

Additional information on the differences between varieties with respect to diastatic power can be obtained by another method. An analysis of variance and covariance of the data on nitrogen in the barley and diastatic power of the malt (see Table VII) shows that

TABLE VII

CORRECTION OF DIASTATIC POWER OF MALT FOR NITROGEN CONTENT OF BARLEY BY ANALYSIS OF VARIANCE AND COVARIANCE

	Correlation coefficient	Regression of diastatic power on nitrogen	Analyses of variance, diastatic power			
			Uncorrected		Corrected	
			Degrees of freedom	Mean square	Degrees of freedom	Mean square
Between varieties	.534		3	1140	3	829*[1]
Within varieties (between stations)	.999**[1]	79	3	8058**[1]	2	13
Interaction	.773**[1]	84	9	407	9	164

	O.A.C. 21	Wisconsin	Peatland	Hannchen	Necessary difference
Uncorrected diastatic power, °L.	144	111	146	122	28
Corrected diastatic power, °L.	149	114	129	130	18

[1] See footnotes, Table I.

within varieties these two qualities are highly correlated. When the coefficient of regression of diastatic power on nitrogen is calculated and used to adjust the analysis of variance for diastatic power, an entirely

different picture is obtained. It becomes apparent, firstly, that practically all of the variance in diastatic power within varieties is associated with a corresponding variance in nitrogen; and secondly, that a large part of the interaction for diastatic power is also associated with a similar interaction for nitrogen. In the corrected analyses the variance within varieties (*i.e.*, between stations) disappears almost entirely, and the relation between the mean square due to average differences between varieties and that due to the interaction is so changed that the former is significantly greater than the latter. It is thus shown that, when comparisons are made at equal nitrogen contents, diastatic power is a varietal characteristic.

The uncorrected varietal means for diastatic power and the means corrected for the effect of differences in nitrogen content are given in the lower part of Table VII. The data show that, when comparisons are made at equal nitrogen contents, the best malting variety, O.A.C. 21, is definitely superior in production of diastase to the other three varieties.

The results of a similar treatment of the data for fine-grind extract and nitrogen are given in Table VIII. Here again it is apparent that

TABLE VIII

CORRECTION OF EXTRACT YIELD OF MALT FOR NITROGEN CONTENT OF BARLEY BY ANALYSIS OF VARIANCE AND COVARANCE

	Correlation coefficient	Regression of extract on nitrogen	Analyses of variance, extract			
			Uncorrected		Corrected	
			Degrees of freedom	Mean square	Degrees of freedom	Mean square
Between varieties	−.192		3	28.31**[1]	3	27.29**[1]
Within varieties (between stations)	−.986*[1]	−4.1	3	22.32**[1]	2	0.93
Interaction	−.900**[1]	−6.0	9	1.50	9	0.40

	O.A.C. 21	Wisconsin	Peatland	Hannchen	Necessary difference
Uncorrected extract, %	76.1	72.4	75.8	78.9	1.7
Corrected extract, %	75.8	72.3	76.6	78.5	0.9

[1] See footnotes, Table I.

the differences in extract yield within varieties are the result largely of differences in the nitrogen content of samples from different stations. However, when the varietal means are corrected for differences in nitrogen content between varieties, there is comparatively little change in the relative positions of the varieties.

A possible method of correcting for unequal modification: One of the limitations of the malting tests used in this investigation is that within each test all samples are malted under essentially the same conditions. These conditions may be better suited to some samples than to others. Thus, the data in Table VI suggest that Wisconsin 38 was penalized by the malting method and that its low extract yield may be the result of insufficient modification.

It occurred to the authors that it might be possible to correct for unequal modification by calculation. The alternative method of attempting to malt all samples to equal degrees of modification presents difficulties which seem almost insurmountable.

If a series of duplicate samples are malted in such a way that the first replicates are definitely less modified than the second replicates, and if a correlation is shown to exist between index of protein modification and extract yield, then it should be possible to calculate by an extrapolation process the extract yield for each sample at the same level of protein modification. The data for tests 1 and 2 appeared to meet these conditions. In the former, extract yields and indices of protein modification were consistently lower than in the latter. The data for the mean values for each sample from these two tests were, therefore, subjected to an analysis of variance and covariance, the results of which are summarized in Table IX. The between-tests correlation between extract and index of protein modifications was found to be highly significant and the regression of extract on index of modification proved to be 0.43%. In the corrected analysis of variance the mean square due to differences between varieties is still significantly greater than that due to the interaction effect which is selected as the best estimate of the experimental error of the investigation. The varietal means were, therefore, corrected with the aid of the coefficient of regression to the values corresponding to the mean index of modification for all samples. The uncorrected and corrected varietal means are given in the lower half of the table, together with the necessary differences required for a 5% level of significance. The outstanding effect of the adjustment is that the position of Wisconsin 38 is materially changed. When the correction is made for under-modification, it becomes about equal in extract yield to O.A.C. 21 and Peatland; the two-rowed variety, Hannchen, retains its superiority. It seems possible that the corrected means now present a better picture of the comparative extract yielding abilities of the four varieties.

It is difficult to estimate whether this method of treating malting data is generally useful and it is apparent that a great deal of investigation would be required in order to determine its validity. There can be little doubt that a correlation exists between extract yield and index of nitrogen modification in the earlier stages of modification, but it appears that a point exists after which, though soluble nitrogen increases slowly, extract yield remains almost constant. It would, therefore, be necessary to work with undermodified malts in applying

TABLE IX

CORRECTION OF EXTRACT FOR DEGREE OF PROTEIN MODIFICATION BY ANALYSIS OF VARIANCE AND COVARIANCE

	Correlation coefficient	Regression of extract on modification	Analyses of variance, extract			
			Uncorrected		Corrected	
			Degrees of freedom	Mean square	Degrees of freedom	Mean square
Between varieties	0.808		3	54.33**[1]	3	19.90**[1]
Within varieties (between stations)	0.962*[1]	0.44	3	39.47**[1]	3	2.92
Interaction	0.567		9	2.75	9	2.66
Between tests	0.848**[1]	0.43	16	3.44	15	1.03

	O.A.C. 21	Wisconsin	Peatland	Hannchen	Necessary difference
Uncorrected extract, %	75.9	71.8	75.4	78.1	1.3
Corrected extract, %	74.2	74.3	75.1	77.6	1.2

[1] See footnotes, Table I.

the extrapolation process. In addition it is assumed that the optimum index of nitrogen modification is independent of the original nitrogen content of the barley, whereas it appears that the proportion of nitrogen made permanently soluble in a properly modified malt decreases with increasing nitrogen content of the barley (Menzel, 1935). Moreover, it is by no means certain that equal degrees of nitrogen modification can be obtained with different varieties of barley. The results of investigations made by Thunaeus and Schröderheim (1935) and of our own study suggest the probability that the proportion of nitrogen which can be made permanently soluble by malting is a varietal characteristic.

In spite of these objections, the application of the analysis of variance and covariance to malting data appears to have some possibilities. It must be admitted, however, that the example reported above proves little.

Summary

Four varieties of barley were grown at four widely separated experimental stations. From the sixteen samples thus obtained, duplicate malts were made by each of four methods representing two laboratory malting tests, a cage method used in conjunction with a Saladin system, and a stocking method used in conjunction with a drum system. All four tests were designed to simulate conditions used in commercial practice in Canada and involve a six-day germination period.

The precision of the four tests was satisfactory and precision was not a limiting source of error in the comparison of varieties. All four tests placed the samples in about the same relative order with respect to each determination made on the malt. Thus, with tests of the type used, tests with a six-day germination period and in which the malts are not overmodified, the differential effect of malting method on samples, although a greater source of error than precision within tests, does not appear to be a serious or limiting source of error in the comparison of varieties. On the other hand, the differential effect of environment on the malting quality of varieties proved to be relatively large and was the limiting factor in the investigation. This, however, was to be expected in view of the wide differences in the environments studied.

Varietal differences were shown to exist with respect to extract, permanently soluble nitrogen, growth, index of protein modification and index of modification by difference between fine-grind and coarse-grind extract; and with respect to diastatic power when varietal means were adjusted for differences in the nitrogen content of varieties. The best malting variety O.A.C. 21 is characterized by the highest diastatic power, fairly high extract yield and permanently soluble nitrogen, together with good growth and ready modification. Peatland, which has also been malted commercially in Canada, is very similar to O.A.C. 21 but does not modify quite so readily. Wisconsin 38, a variety which Canadian maltsters consider unsuited for their purposes, is low in extract, diastatic power and permanently soluble nitrogen, and its growth and modification are poor. Hannchen, a two-rowed variety, is high in extract but low in permanently soluble nitrogen and growth. It does not modify adequately within a six-day germination period.

Within each test all samples were malted under essentially the same

conditions with the result that inequalities in the modification of different samples occurred. A possible method of correcting these inequalities by application of the analysis of variance and covariance is suggested and an example is reported.

Acknowledgment

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REPORT OF THE 1936–37 A. A. C. C. COMMITTEE ON STANDARDIZATION OF LABORATORY BAKING

C. F. DAVIS, *Chairman*

The Western Star Mill Company, Salina, Kansas

(Read at the Annual Meeting, May 1937)

Early in the work of the Committee on Standardization of Laboratory Baking its efforts were directed by that logical construct of the cereal chemist's mind that a standard baking test of a fixed nature was essential to a more common understanding of flour baking characteristics. The goal of standardization has been placed before the various committees by provisions in the constitution of the Association and the title of the committee itself. The term "standard" as it applies to a test procedure may imply that it is the test used by a regulatory organization, that it is in general use due to its unquestionable status, or that it is the product of universal agreement. Our goal in standardization is only to construct a testing method which, by its scientific reliability, efficiency and widespread use, will promote a more common understanding of the baking properties of flour and a closer relationship between the results of various test bakers.

Standardization of a test involving such a variety of factors as does the baking test is complicated in many respects. Lundell (1933), referring to testing systems containing several components, states that they can hardly be handled on a strict, scientific basis, and any handling of them requires actual experience in analysis. The reasons for test baking, the type and mode of procedure to follow, the details of the procedure, development of efficient and economical equipment, the establishing of formulas, reporting and interpretation of results all need definite consideration when we endeavor to standardize the laboratory baking test.

Reasons for Test Baking

It is generally recognized that baking tests serve two major purposes—first, the determination of the flour characteristics that cannot be determined otherwise, and second, on the basis of all characteristics of the flour to find the baking method best suited to it under a given set of conditions. Under the first heading we use principally an analytical type of test in which we endeavor to fix and maintain conditions and factors and introduce the flour as the variable to learn its

reaction. We have made much progress in applying specific tests to flour and thereby have eliminated the need for resorting to some of our analytical baking tests in instances where we are thoroughly acquainted with the meaning of the specific test in terms of its baking significance. The basic test formula as originally designed was an estimate of the diastatic activity of the flour, but since we have more efficient ways of measuring this factor it is common practice in test baking to supply sufficient sugar, diastatic supplement, or to reduce the yeast percentage to eliminate this factor from the baking results and determine other more elusive breadmaking characteristics. We determine optimum conditions for attaining the best results and the ranges through which it is possible to secure acceptable products from each flour. The experimental results are expressed in a concrete manner for purposes of laboratory control of uniformity and quality, and for other purposes are expressed as abstract flour properties without reference to the specific use of the flour. Under the second heading we assemble the chemical analyses, physical measurements and baking properties as determined by analytical baking tests and reduce them to concrete information to construct in any specific set of conditions the optimum or standard loaf held as an objective.

Type of Procedure

The definitions we apply to the terms which describe the two schools of thought relative to the manner in which we approach our objective in test baking are a source of controversy. There are those who claim to adhere to a "fixed type" of testing procedure and our A. A. C. C. standard basic procedure is generally classified under this heading. There are those who feel that the problem should be attacked with a "variable type" procedure. If standardizing the laboratory baking test is to proceed in a rational manner as an association activity, we must utilize both types of procedure. The importance of the subject of fixed and variable types of procedure seems to justify that they be discussed with reference to this committee's work in the light of our present knowledge of test baking. Logically a rigidly fixed procedure would appear to fit best into a standardization program and assist an operator in testing a large number of samples. This is the type of test previous baking committees attempted to establish. For example, a definite amount of water was originally specified for the basic formula, but experience found that flour characteristics with reference to absorption required that this be changed. At present we specify that water be added to proper dough consistency as judged by the test bake operator. Instead of feeling that we have destandardized the test, we believe we have improved its status by recognizing that flours differ

with respect to absorption and that the test method must conform to the subject under test. We would rather risk our judgment (from lack of a more accurate method) on absorption than allow a maladjustment of this factor to carry through the entire test. This condition exists with reference to the degree of mixing, and it has been proposed that we specify only the type mixer to use and not the mixing time which should be regulated by the flours' requirements. Our present standard test is not a rigid fixed procedure as the terms "standard" and "fixed" would imply for more simple testing methods, and in the development of our test fixed factors and means of determining and maintaining them are to have a place as part of the test. It would be a coincidence if the biological processes with which we deal were cognizant of the arbitrary units of weight, measure and time which we might rigidly set up for a test. Even in many inorganic testing procedures, the method of testing is adjusted to the percent composition and the nature of the impurities in the sample being tested. Such a procedure is not unscientific and it has application in other scientific fields. Our American grade school system was developed with the idea of providing equal opportunities for all children of this democracy. A standard graded system has its usefulness in terms of economy and organization in mass application, but the most scientific educational systems today recognize that children's capacities vary, and school systems must be made to conform to the requirements of the child as much as possible within the limits of practical operation.

In recognizing flour characteristics we are not necessarily attempting to manufacture a product along with the test, but we are trying principally to eliminate the probability that certain factors would be poorly adjusted to the procedure and in the end mask the effect of other factors about which we are less certain and which we are attempting to measure. We must emphasize the fact that a standard basic test is only one of a series of analytical baking tests, and that any single baking test is very limited in application. In the test baking requirements for some flours, the percent basic formula may not be in the proper range of treatment to be most useful even as an analytical test, and for that reason it has, in the hands of many, undergone considerable modification. Since the most important use of the standard basic test is to provide a common starting or reference point in test bake studies, it has been suggested from several sources that amendments be made to the basic formula to promote its more general use with full recognition that we cannot hope to establish arbitrarily one basic test or zero point to meet all the varied requirements of test bakers.

Those who like to apply a broad variable type of test baking procedure have a wide field for exercising their ability in test baking. The numerous factors involved in the test and the almost limitless combinations that might be studied and applied to the flour make it imperative that the "variable type" test adherent fix many testing conditions and proceed with a study of the more important variables on a practical, workable basis so that their influences can be segregated and measured. Perhaps the most advanced and scientific test baking scheme is one that follows the Latin square, "multiple differential" or "checkerboard" design of experiment in which the significance and inter-relationships of several factors can be determined. Because of the multiple correlations of factors affecting dough structures, such a scheme is essential to comprehensively understand and locate the optimum and tolerance values of flour. One can easily design these experiments involving so many variables that it is impractical to carry them out, or the scheme can be reduced to the study of a few variables or treatments and be practical for the average test baker. The standard A. A. C. C. baking test lists the variable features of the test under the heading of supplements to be applied one at a time. This arrangement is easier to carry out than when two or more treatments are applied in the same experiments, but we lose the measure of the inter-relations of the factors or treatments as they actually exist.

Thus we can see that our scheme of attack on our test bake objectives must be a compromise between a relatively simple single procedure conveying a limited amount of the information we want and an elaborate system which we can easily plan beyond the capacity of our ability to perform in a practical manner.

Details of Procedure

This report does not attempt to concentrate on the minute details of the test baking procedure, but to outline in general the problems concerned and the nature of the approach to their solution.

The specific objective of the test will in a measure determine the outline of the procedure. In well controlled test baking, we do not approach the flour as a totally unknown substance. We have certain analytical data and specific tests for guidance. Knowing the moisture content of the flour we proceed with 85 g. of dry matter or multiples thereof in calculating the formula and to obtain a quantity of dough most suitable for thorough mixing action. With a specified mixer we should specify the optimum amount of flour to use for the mixer capacity and aliquot the dough for tests. When we have our flour and ingredients incorporated and our degree of mixing estimated, we might well consider that we are testing dough and not flour.

The fermentation of the dough and its behaviour in the oven are the major reactions with which we are concerned. The fermentation of the dough may be divided into the headings of gas production and gas retention. It is probable that our knowledge of gas production factors is farther advanced than our information on gas retention factors. Because of our limited knowledge in both of these categories, it is quite common practice to vary the fermentation time (supplement 1) with formula adjusted so that possibilities of sugar depletion are eliminated and obtain a running summary of the forces acting in the dough. If the dough could express itself in a versatile manner, then we might find a focal point in the play of forces to justify the selection of definite fermentation times.

We are possibly not ready to standardize a method to pan-proof the dough. Proofing to time simplifies the procedure in putting a large number of samples through a time schedule, but since the rate of gas production varies with different flours and formulas causing dough-pan relationships to vary and loaf type and interior to be affected, it appears very logical that we should put doughs in the oven after they have been impregnated with a definite amount of gas. Proofing to height is a common practice that approaches this specification. All factors that we do not care to measure, and which materially affect the results, should be compensated for to allow us to simplify our test and build up common understanding of the factors we must study.

Equipment

One of the key factors leading to the goal of standardization is further mechanization of the test. In the development of machines the experimental stage requires a number of years and may be considered to be in a constant state of flux. In recommending or adopting equipment we should feel reasonably sure that the machine would not be superseded by better equipment within a period of 10 to 12 years, so that the investment would be justified. With our baking studies built around any particular machine or procedure, there is a strong tendency for it to remain long after better replacements are available. Since in the determination of the relative value of test baking equipment we must subject it to experimental tests having rather high experimental errors, it may be difficult to establish definitely small improvements and points of superiorty. We are handicapped by not offering a large market which would stimulate competitive development of efficient equipment.

After endeavoring to standardize the baking test for more than a decade, we have specified an official dough mixer (which has not been readily available and has no specified R.P.M.), an official dough

thermometer, an official oven thermometer, and two official baking pans along with other recommended equipment. Experience has shown that the personal factor is very pronounced in the punching and molding stages of the procedure and that pan differences are significant. One commercial molder suitable for 160-g. doughs is offered at an almost prohibitive price. Two other molding devices (Malloch and Hopkins, 1935, and Van Scoyk, 1937) are being developed which could be offered at a reasonable figure. This committee can only offer encouragement to such development by surveying the possible demand for such equipment and providing adequate cooperative study of the usefulness of the machine. One standard baking pan would show a more consistent effort toward standardization.

According to our best information to date, we might well specify the conditions for the baking environment, but rigid oven specifications should await more knowledge of the oven factors contributing to the baking reaction. An experimental experimental oven would help us in definitely specifying our oven requirements.

In the complete mechanization of the baking test, we should consider that some of the most successful test bakers have gained much of their information from the manual operations in handling the dough, and we shall lose this source of information unless we can substitute equal or better measurements of the dough properties through mechanical tests. Individual talents vary in judging dough and the mechanical evaluation would promote greater uniformity among cereal workers.

Test Bake Formulas

The formulas used in test baking may vary from lean to rich with ingredient combinations so numerous that it is necessary to be selective and fix or calculate formulas in an effort toward standardization. Lean test formulas with higher percentages of yeast are proposed to more strenuously test the flour, and rich formulas are used with the idea of determining the flour's ability to carry the load of ingredients. To pattern our formula after an average commercial formula would give us a shifting contemporary standard which for practical purposes might be advisable but for defining flour properties might lead to a chaotic state in our reference data. The present basic formula has been criticized in the following respects: percent of yeast is too high; percent of salt is too low; shortening should be included; sugar should be adjusted to the diastatic value of the flour; and some would even include milk in the formula. It is interesting that there has been no definite criticism of the size of the loaf. Our revision of the basic formula with respect to ingredients should be justified by experimental evidence and consideration that we should make the test useful to as

large a number as possible as a zero point or point of departure in applying other treatments. Our basic formula might well be a compromise between the lean and rich formula with the two extremes used as supplements to bring out flour characteristics of a specific nature. Formulas for these special tests, such as for experimentally milled flours and special wheat classes, together with specific information, might well be presented in an appendix to the outline for the standard procedure.

Reporting and Significance of Results

It has been paramount in the aim of the various baking committees to develop a method giving concrete results which would permit flour characteristics to be reported and expressed in simple and universal terms that would be dependable. The terms expressing optimum and tolerance values do not readily lend themselves to simple expression. It was hoped that loaf types (Blish, 1928) could be used to simplify reporting the baking test results and express flour characteristics in an abstract manner. Loaf types do save descriptive terms in reporting the nature of the finished loaf, but for the purpose of defining flour characteristics in an abstract manner they may be meaningless. The A. A. C. C. Baking Fellowship report states that doubtless much of the significance attached to loaf characteristics in bread scoring is fictitious rather than real. Geddes and Larmour (1933) found that the addition of heat-treated germ, addition of bromate and extended fermentation produced the same trend in baking behaviour and, when combined, resulted in an over effect. The relationship of the top of the dough to the top of the pan when the loaf goes to the oven has a significant bearing on the type of loaf. For example, when we look at a Type H loaf we do not know the causes of this appearance because the finished loaf by itself cannot express its story in a versatile manner and the condition of the loaf may be the result of any one of several factors. The baking test is a test of experience in which the things we can observe are the only things we really know, and in reporting the results it appears that we cannot hope to limit our observations to a finished loaf, good or bad. Our laboratory recording of results may make use of loaf volume, texture, grain, and loaf type as various test end-points, but our reporting to others must begin from the beginning of the test with more general expressions; for example, absorption 62–63% (15% M.B.); mixing 2.5 minutes (optimum or peak of development in Hobart-Swanson mixer), short mixing tolerance; gas production critical point (80° F., 3% yeast) 4 hours;—optimum fermentation, long, medium or short time with broad or narrow range (according to where best texture and grain are obtained with acceptable loaf

volume); maximum bromate response at 0.002% (loaf volume 640 c.c., basic loaf 570 c.c.), tolerance 0.001% to 0.004%; nature of dough as to degree of stickiness, elasticity, toughness and extensibility, etc.

When we attempt to provide an adequate system of reporting results, the following statements must be considered: Larmour (1929) states that baking data would be more useful if accompanied by some expression of the operators' conclusions. Alcock (1936) states that usually it is best for the baker or the one to whom the report is made to consult the chemist responsible for the laboratory report. Ordinarily chemists in talking over the results of their baking tests have little trouble in conversing with each other in an understandable manner and it appears that with a few of the more usable terms clearly defined for the Association, there are strong hopes that the test baker can convey his data to those responsible for bread production so that they will be useful.

Interpretation of the results of our standard testing procedure has been a serious difficulty in many attempts to use the test. Only if we can correlate our experimental findings with bakeshop practice may we hope to interpret our results so that they will be significant in bread production. In studying such correlations it is advantageous to have the two subjects in the same category as nearly as possible. It is for this reason that pilot plants are so useful in the baking industry and in all industry. Most flour in this country is utilized in sponge dough production and between such a procedure and our small loaf straight dough procedure is a wide gulf that we are possibly attempting to span with broad assumptions in making our interpretation. The replies to the questionnaire sent out by Aitken (1934) indicated a general demand for an experimental sponge dough procedure. This demand has grown until the baking committee proposes immediately to take steps toward tentatively outlining such a procedure. Our information on interpretation should build up more readily as we correlate small straight dough exhibitions with small sponge dough results and in turn correlate these with pilot and actual bakeshop practice. From agronomist to baker we should work for information which can be expressed in universal terms and which is pertinent to the ultimate utility of the flour.

Future of the Standard Baking Test

To obtain a cross-section view of Association opinion with respect to the status of the work of the Committee on Standardization of Laboratory Baking and the course which it should follow, a questionnaire was submitted to thirty members who were in position to give an

opinion on the subject. Replies to two of these questions may be summarized as follows:

Q. 1. Are you in favor of a fixed (fixed as to controllable factors and conditions) basic procedure as a reference point and supplementary tests as embodied in the present A. A. C. C. Standard Baking Test?

A. Yes, 17; no, 4; indefinite, 2; no reply, 7.

Q. 2. Should we consider the present standard basic test as official or tentative?

A. Official, 7; tentative, 14; neither, 2; no reply, 7. Comments through the replies indicate that there is a definite though not unanimous demand for continuing the efforts toward standardization of the baking test. The suggestion that we proceed on a tentative basis is perhaps in recognition of the fact that we have much unfinished business with regard to standardizing items that can and should be standardized, and also in consideration of the fact that we should await more definite information relative to some factors about which we are not certain as to the wisdom of standardizing at this time.

By placing the goal of standardization further ahead and by persistently applying ourselves to the problem, it has been suggested that after 10 to 20 years we may be in better position to formally endorse a scheme of test baking that would more nearly meet our requirements and ambitions. We may find that partial rather than complete standardization is preferable. We are dealing with things ranging from inorganic matter to philosophy, and we may encounter obstacles that will not vanish by any authority the Association may assume or information it may formulate. To diligently approach a goal which broadens our concepts and improves the status of test baking is worthy of our efforts.

Recommendations

That the present standard baking test be given a tentative status.

That the Committee on Standardization of Laboratory Baking continue its efforts to develop a standard test baking procedure and basic formula or formulas with supplements to be applied in the most advantageous manner.

That special attention be given to the development and testing of equipment with the aim of definite standardization of such items as mixer, molder, pans and oven.

That the construction of special formulas be studied with reference to correlating the flour properties of commercially and experimentally milled flours.

That laboratory sponge dough procedures be investigated by the committee.

That an appendix be added to the standard A. A. C. C. Bread Baking Test in *Cereal Laboratory Methods* expanding on the limitations and extensions of the method with reference to its objectives.

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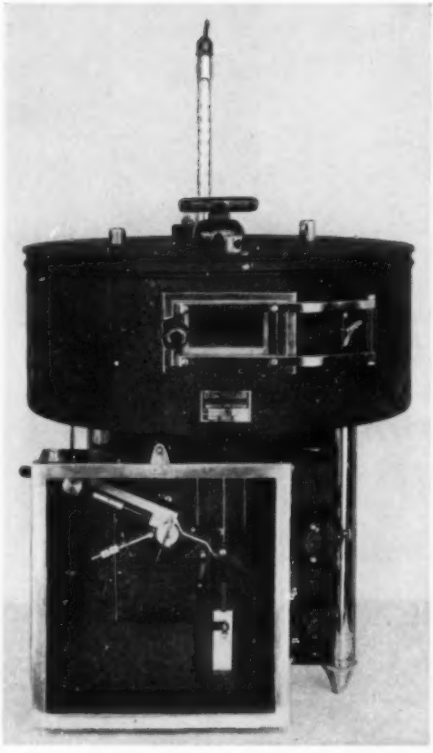

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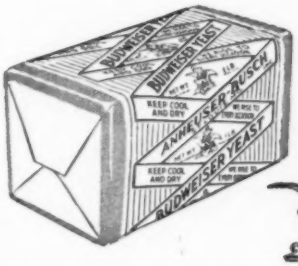

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